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The *American Journal of Alternative Agriculture* provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.

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The *American Journal of Alternative Agriculture (AJAA)* was launched in 1986 by the US-based Institute for Alternative Agriculture, a nonprofit organization established in 1983. Renamed the Henry A. Wallace Institute for Alternative Agriculture in 1993, this organization became part of Winrock International in 2000. The *AJAA* was published for 16 years by these three founding and successor institutions. The Henry A. Wallace Center for Agricultural & Environmental Policy at Winrock International continues to advise CABI *Publishing* on matters relating to the future shape and direction of the journal.

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Editorial
Our Common Goal: Renewing Earth and Its People

The *American Journal of Alternative Agriculture* (AJAA) has become an international forum for original research articles on the biological, physical, social science, and policy aspects of alternative agriculture since its inception in 1986 by Garth Youngberg, then Director of the Institute for Alternative Agriculture. It is an honor for me to serve as Editor-in-Chief of this pioneering journal. The AJAA was one of the first scientific journals to focus on multidisciplinary approaches to understanding the character and potential of sustainable and organic farming systems as alternatives to industrial, chemical, and fossil fuel-based agricultural systems. A special thanks to Dr William Lockeretz for his 10 year leadership and forethought as technical editor in assuring clear definition of terms and concepts related to organic farming and sustainable agriculture. I also thank my immediate predecessor, Professor Robert Papendick, for the high standard of scientific quality that he set and maintained for the journal. Appreciation is also extended to Dr Kate Clancy and the staff at the Henry A. Wallace Center for Agricultural & Environmental Policy at Winrock International for their long-time publication of the journal and for continued suggestions as the journal takes on new shapes and directions under CABI *Publishing*. I embrace the challenge we all face in science in adapting to the rapid social, economic, and technological changes that will come. Agricultural and food production systems must continually change to meet the multiple economic, social, ecological, and environmental needs of earth and its people.

Over fifty-some years on this earth I've witnessed doubling of the world's population, a widening gap between the rich and poor, unprecedented climate change, environmental degradation, and a re-evaluation of energy use and alternatives. I attended school during the 'green revolution.' Scientific and technological advancements have allowed us to produce two to three times more food per unit area of land, saving perhaps one billion people from starvation and postponing expansion of agriculture into more fragile lands. However, when applied as one-dimensional, single-tactic approaches for increasing production of major grain crops, these technologies have reduced biological diversity, increased dependence on fossil fuels, and added large quantities of chemicals to the environment. These practices have degraded our water, soil, and atmosphere. In the past half-century, agricultural intensification has resulted in degradation of over 25% of the world's agricultural land, pastures, woodlands, and forests. Intensive production methods have led to transport of nitrogen and phosphorus from watersheds to rivers and groundwater and caused eutrophication of surface and coastal waters. We have witnessed a dramatic increase in the release of greenhouse gases caused by soil cultivation, fertilization, and increased use of fossil fuels.

Current industrial approaches to food production and distribution also fail to meet the needs of all people. Global food supplies per person are at their greatest level and are sufficient to meet the nutritional needs of all, if food were distributed on a per capita basis. But the fact is that 20% of the world's population appropriates over 80% of the wealth and resources. The remaining 4.8 billion people have access to less than 20% of the resources; 1.2 billion people earn less than one U.S. dollar per day and 800 million don't know from where their next meal will come.

In the 21st century, we are again challenged to produce and distribute food for a global population one-and-a-half to two times its current size. As agricultural systems grow to meet the demands of more people, increased pressure is placed on our natural resources. Competition for land, water, and energy resources from both urban and industrial sectors becomes more acute and the land base for agriculture shrinks. Under

current practices, greater food production will increase inputs into agricultural production systems, opportunity for environmental pollution, and degrade and deplete natural and non-renewable resources.

To sustain agriculture and the world for future generations, we must act *now* to develop production systems that rely less on non-renewable, petrochemical resources; rely more on renewable resources from the sun for our food, feed, fiber, and energy needs; and achieve the ecological intensification needed to meet the increased future commodity demand. To achieve this end, we need an understanding of farmers' needs and constraints to develop policies that will support and enable the adoption of these new systems. Better understanding and creative use of natural processes for meeting our food and energy needs will require lifestyle change to achieve the multiple goals of economic, ecological, and environmental sustainability. One highlight at a 'Soil, Food, and People' Conference at the University of California at Davis (March, 2000) was that needs of all people, including the poor and disenfranchised, can be met by alternative forms of production such as biointensive agriculture, if appropriate lifestyle changes are adapted. This system of farming has been effective in over 100 countries, meeting the basic nutritional and caloric needs of people while conserving or building soil, environmental, and natural resources. Biointensive Agriculture, as with other alternatives such as Natural Systems Agriculture, cannot presently be assimilated into the mainstream of modern agriculture and industrial structure. Both can provide useful models for the direction of future agriculture and will be needed if we are to achieve the vision of sustaining the soil, the earth, and its people.

Agriculture needs economical soil management practices that provide sufficient food and fiber while maintaining environmental stability, ecological integrity, and the quality of essential soil, water, and air resources. Our quest for sustainable land management starts with identification of the final destination or goal, proceeds to devising strategies or courses by which they can be achieved, and is confirmed by development of indicators that we are going the right direction. The health of our soil resources is a primary indicator of the sustainability of our land management practices. Strategies for sustainable management include conserving soil organic matter, minimizing erosion, balancing production practices with environmental needs, and making better use of renewable resources. To employ these strategies, however, we must first translate them into practices that are beneficial and accessible to producers. The condition of our soils ultimately determines human health by serving as the major medium for food and fiber production and a primary interface with the environment, influencing the quality of air we breathe and water we drink. There is a clear linkage between soil quality and human and environmental health. There are many other factors in the food system that also determine human health and the integrity of nations to care about their soil and land resources.

I look forward to my tenure as Editor-in-Chief of *American Journal of Alternative Agriculture*. The journal will undergo changes within the next year to reflect a broader audience and mission of moving us forward from recognized needs for agricultural alternatives to conventional agriculture to an enhanced vision for an agriculture that will renew the earth and all its people. To this end, I welcome Dr Wallace Wilhelm as Resources Review Editor and thirty new Associate Editors as listed on the inside cover. The breadth of experience and diversity of our editors is remarkable and includes international leaders in the physical, social, and earth sciences; four farmer practitioners; and many leaders of sustainable, organic, biological, and natural systems agriculture. My personal vision is for a world in which our scientific and technological breakthroughs are used to benefit the health, safety, and community of all people.

John W. Doran

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Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use

Ray R. Weil, Kandikar R. Islam, Melissa A. Stine, Joel B. Gruver and Susan E. Samson-Liebig

Abstract. *A simple method of estimating changes in biologically active soil carbon (C) could help evaluate soil quality impacts of alternative management practices. Most reports of permanganate for active C determination use highly concentrated solutions (0.333* M*) that are difficult to work with and tend to react with a large fraction of soil C that is not well distinguished from total organic C. We report on a highly simplified method in which dilute, slightly alkaline* $KMnO_4$ *reacts with the most readily oxidizable (active) forms of soil C, converting Mn(VII) to Mn(II), and proportionally lowering absorbance of 550 nm light. The amount of soil C that reacted increased with concentration of* $KMnO_4$ *used (0.01 to 0.1* M*), degree of soil drying (moist fresh soil to air-dried for 24 hour) and time of shaking (1–15 minutes). Shaking of air-dry soil in a 0.02* M $KMnO_4$ *solution for 2 minutes produced consistent and management-sensitive results, both in the laboratory and with a field kit that used a hand-held colorimeter. Addition of 0.1* M $CaCl_2$ *to the permanganate reagent enhanced settling of the soil after shaking, eliminating the need for centrifugation in the field kit. Results from the laboratory and field-kit protocols were nearly identical (*R^2 *= 0.98), as were those from an inter-laboratory sample exchange (*R^2 *= 0.91). The active soil C measured by the new procedure was more sensitive to management effects than total organic C, and more closely related to biologically mediated soil properties, such as respiration, microbial biomass and aggregation, than several other measures of soil organic C.*

Key words: active soil carbon, analytical methods, field kit, microbial biomass, permanganate oxidizable carbon, soil organic matter, soil aggregate stability, soil quality assessment, soil quality indicators

Introduction and Background

Soil organic matter (SOM) and related soil properties are probably the most widely acknowledged indicators of soil quality (Gregorich et al., 1994; Wander and Drinkwater, 2000). Since SOM has no definite chemical composition, soil organic carbon (SOC), the dominant elemental constituent of SOM, is more commonly measured and reported in scientific literature. Soil organic C is naturally variable across landscapes, soil types and climatic zones. It is generally characterized by high levels of C in recalcitrant or humified forms. Small changes in SOC resulting from changes in soil management are often difficult to measure, but can have pronounced effects on soil behavior and microbial processes. It may take many years for contrasting soil management practices to cause measurable differences in SOC (Sikora et al., 1996).

Changes in small but relatively labile fractions of SOC may provide an early indication of soil degradation or improvement in response to management practices. The labile fractions of soil C are important to study in their own right as these fractions fuel the soil food web and therefore greatly influence nutrient cycles and many biologically related soil properties. The labile fractions of soil C are often termed the active C pool, to distinguish it from the bulk of the soil C, which belongs to a highly recalcitrant or passive C pool that is only very slowly altered by microbial activities. Fractions of SOC that are thought to represent the active C pool, and serve as sensitive indicators of changes in management-induced soil quality, include microbial biomass C (Islam and Weil, 2000; Kennedy and Papendick, 1995), particulate organic matter (Janzen et al., 1992; Wander and Bidart, 2000) and soil carbohydrates measured as anthrone-reactive C (Deluca and Keeney, 1993; Saviozzi et al., 1999).

Scientists, extensionists and farmers are increasingly interested in making simple assessments of soil quality in the field, to help guide management decisions (Liebig and Doran, 1999; Wander and Drinkwater, 2000). The USDA Natural Resources Conservation Service (NRCS) has

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therefore developed several tools for field assessment of the impact of management practices on soil quality, including a qualitative Soil Health Assessment Card (USDA–NRCS, 1999) and a more quantitative Soil Quality Test Kit (USDA–NRSC, 1998). The current version of the NRCS Soil Quality Test Kit contains tests for nine soil parameters (USDA–NRSC, 1998). However, it does not include any test for either the active fraction or total SOM or SOC. Determinations of such labile C fractions as particulate organic matter, extractable carbohydrates or rapidly mineralizable C are time consuming and require complex laboratory manipulations that limit their use. Total SOC content can be readily determined in the laboratory by wet acid dichromate oxidation (Islam and Weil, 1998b; Walkley and Black, 1947), CO_2 released by dry combustion (e.g., LECO Corp. CHN Analyzer) and loss of mass on ignition (Magdoff, 1996). However, a practical field test for total or active organic C is not yet available.

In earlier work, Islam and Weil (1997) showed that anthrone-reactive C, extractable after a short-term microwave treatment, was a good predictor of a soil quality index that integrated 11 physical, biological and chemical soil properties. However, there are several limitations of the anthrone-reactive C as a measure of soil quality:

- the procedure requires expensive laboratory equipment (microwave oven, water bath, shaker, centrifuge, spectrophotometer, etc.);
- the anthrone reagent is both unstable and a toxic irritant containing concentrated H_2SO_4, which is too hazardous for routine use in the field;
- the results show poor repeatability and high sensitivity to operator technique; and
- the anthrone reaction is subject to interference by such common soil constituents as Cl^-, NO_3^- and Fe^{2+} (Doutre et al., 1978; Johnson and Sieburth, 1977).

Other colorimetric methods for measuring sugars in soil, using such reagents as *p*–hydroxybenzoic acid hydrazide (PHBAH) and bisodium bicinchoninic, are described in the literature (Joergensen et al., 1996; Lever, 1972), but each has its own limitations concerning complexity, toxicity, equipment requirements and/or lack of reproducibility, and lack of sensitivity to soil management practices affecting soil quality.

In contrast, potassium permanganate ($KMnO_4$) has many characteristics that are propitious for a routine field method. The intense purple color of the $KMnO_4$ solution enables it to serve as its own indicator. If properly prepared and stored, permanganate solutions can be stable over several months (Swift, 1939). It is so safe to handle that solutions ranging from 0.006 to 0.3 *M* are recommended in human and veterinary medicine as an antiseptic treatment for skin infections and wounds (Brander et al., 1982).

In a neutral to slightly alkaline solution, potassium permanganate ($KMnO_4$) is a powerful oxidizing agent because of the large negative value (–1.45 V) of the potential between the Mn^{2+} and MnO_4^- ions (Cotton and Wilkinson, 1965). At pH 7.2, portions of SOC react with $KMnO_4$ to partially bleach the deep purple permanganate color to light pink or clear (Loginow et al., 1987). Specifically, slightly alkaline $KMnO_4$ is known to hydrolyze and oxidize simple carbohydrates, amino acids, amine/amide sugars, and C-compounds containing hydroxyl, ketone, carboxyl, double-bond linkages and aliphatic compounds, to give a light pink color (Loginow et al., 1987; Skoog and West, 1969; Stanford, 1978). Lefroy et al. (1993) used several concentrations of $KMnO_4$ in an attempt to measure soil C fractions that were related to such soil quality properties as aggregation and infiltration. From these results, Blair et al. (1995) concluded that only one $KMnO_4$ concentration (0.333 *M*) was needed to distinguish labile soil C (oxidized by $KMnO_4$) from recalcitrant soil C (not oxidized by $KMnO_4$). They compared the relative size of these two C fractions in cropped soils to those in nearby uncultivated 'reference sites', to derive a C management index for agricultural systems.

To date, most research on $KMnO_4$-reactive soil C has used the 0.333 *M* $KMnO_4$ method of Blair et al. (1995) to oxidize a fraction of soil C considered active or labile. Blair et al. (2001) report that this reagent appears to react with a relatively labile pool of soil C, and that changes in soil management often influence 0.333 *M* $KMnO_4$-reactive soil C more markedly than they do total SOC. Significant correlations have been reported between 0.333 *M* $KMnO_4$-reactive C and several soil chemical and physical properties (Bell et al., 1998; Blair and Crocker, 2000; Blair et al., 1995; Moody et al., 1997; Whitbread et al., 2000). However, at this high concentration, $KMnO_4$ reacts with a rather large fraction of the total SOC [14–27% of the total organic carbon (TOC) in the 13 soils described by Blair et al. (1995)], rather than with just the most labile fractions. In three of the four cases presented by Lefroy et al. (1993), the C reactive with the tenfold more dilute 0.033 *M* $KMnO_4$ showed a greater relative decline with long-term cultivation than did the fraction reactive with the 0.333 *M* solution.

The 0.333 *M* solution may therefore be better suited as a simple estimate of total organic C than as an estimate of the labile C fractions associated most closely with soil quality. For example, using a range of highly weathered Australian soils, Bell et al. (1998) reported on the relationships between fractions of soil organic C oxidized by 0.033 *M*, 0.167 *M*, and 0.333 *M* $KMnO_4$ solutions and certain critical soil physical and chemical properties. The soil organic C fraction most closely correlated with the properties deemed critical to the quality of these soils (aggregate stability, infiltration rates and effective cation exchange capacity) was that oxidized by 0.033 *M* $KMnO_4$. These researchers suggested that sustainable cropping on these soils would require management practices that maintain adequate concentrations of 0.033 *M* $KMnO_4$-oxidizable soil C.

In addition to the relatively low sensitivity to changes in C cycling just discussed, the Blair et al. (1995) method using 0.333 *M* $KMnO_4$ involves several important limita-

tions that we attempted to overcome in developing a simplified, improved method for determination of active soil C in both laboratory and field settings. First, their procedure requires relatively extensive equipment, many time-consuming steps and a laboratory setting for soil grinding, volumetric measurements, shaking, centrifugation, filtering and visible light spectroscopy. Second, 0.333 *M* is close to the limit of $KMnO_4$ solubility (0.40 *M*). This highly concentrated solution is both difficult to prepare and maintain and somewhat hazardous to use.

Objectives

The objectives of our study were:

1. To develop a rapid, reproducible and safe method for measuring a soil C parameter that would be a sensitive indicator of management-induced soil quality changes.
2. To simplify this method for use in a user-friendly kit that farmers and conservationists could use in the field. This objective required a method that would not require elaborate equipment and would use a minimum number of reagents, none of them highly toxic, hazardous or unstable.
3. To evaluate the suitability of the method for use on soils with a wide range of properties, and assess the relationships between the measured C fraction and soil microbial properties.

Our hypotheses were that:

1. A $KMnO_4$ solution considerably more dilute than 0.333 *M* would consistently react with a smaller and more labile C fraction.
2. The C measured by the dilute $KMnO_4$ solution would better reflect soil management effects and microbial activity.
3. The dilute solution would be easier to prepare and maintain and would require fewer dilution steps to bring it into a range of absorbance readable on an inexpensive hand-held colorimeter.
4. The fine grinding, weighing, mechanical shaking, centrifuging and filtration steps could all be eliminated in a simplified method without seriously degrading the precision or accuracy of the results.

Materials and Methods

Soils used

A total of 209 surface soil samples were used to evaluate various aspects of the proposed method. These soils either represented farm fields or experimental plots in Maryland (38 farm fields and 12 experimental plots), New Jersey (4 farm fields), North Dakota (9 experimental plots), Pennsylvania (23 farm fields and experimental plots), central Honduras (105 on-farm plots) and southern Brazil (16 farm fields). All sites were in agricultural use, but tillage regime, crop rotations and organic amendments varied. The samples therefore represented a range of management systems, including conventionally plowed continuous corn (*Zea mays* L.), heavily compost-amended organic fruit orchard, and lightly grazed native prairie. The soils were classified in the soil taxonomy suborders Udults, Udepts, Udox, Ustolls, Ustepts, Udalfs and Ustalfs. They ranged in pH from 4.5 to 7.4, in clay concentration from 150 to 500 $g\,kg^{-1}$, in clay mineralogy from kaolinitic to smectitic, and in total organic C concentration from 4 to 69 $g\,kg^{-1}$. All samples were composite samples obtained from the upper 7.5 cm of soil, except the nine North Dakota Mollisol samples, which represented the upper 15 cm of soil.

Modifications to the permanganate oxidizable C method of Blair et al. (1995)

We substantially modified the Blair et al. (1995) 0.333 *M* $KMnO_4$ method to develop a $KMnO_4$ oxidation method that would be more sensitive to the effects of soil management, more rapid, reliable and user-friendly to carry out, and suitable for routine use in a field kit. The procedural factors modified and evaluated were as follows.

Molarity of $KMnO_4$ solution used to react with the active soil C. We aimed to find a solution concentration that would be easier to make and handle than the 0.333 *M* $KMnO_4$ solution prescribed by Blair et al. (1995) and that would react consistently with a management-sensitive labile C fraction in soils. To do so, we tested a series of $KMnO_4$ solutions, ranging from 0.005 to 0.1 *M* (adjusted to pH 7.2), using a set of soil samples from a minimum tillage treatment and a conventional plow tillage treatment from a long-term replicated experiment. Continuous corn grain had been grown for on these plots for 15 years. The soil was a Hagerstown silt loam (Ultic Halplustalf). We reacted 1.0 g oven dry equivalent (ODE) of air-dried soil with 20 ml of neutral $KMnO_4$ in water at concentrations of 0.005, 0.01, 0.0125, 0.025, 0.05 and 0.1 *M*. The soil–$KMnO_4$ suspensions were shaken at 200 rpm for 15 min at room temperature in screw-cap polycarbonate centrifuge tubes. After shaking, the tubes were centrifuged at 3000 rpm for 5 min to separate the soil particles from the solution. We then transferred 0.20 ml of the clear centrifugate to a glass cuvette tube, diluted with 10.0 ml of distilled water, using a strong stream to assure complete mixing. We measured the absorbance of 565 nm light using a Bosch and Lomb 2500 spectrophotometer and compared the absorbance readings to a standard curve constructed using 0.20 ml of each unreacted $KMnO_4$ solution plus 10.0 ml distilled water.

Absorption wavelength and standard curve. To determine the most effective wavelength for measuring changes in absorbance by $KMnO_4$ solutions as a result of reacting with soil C, we constructed standard curves using 1 ml aliquots of 0.005, 0.01 and 0.02 *M* $KMnO_4$ (adjusted to pH 7.2) diluted to 50 ml with distilled water. We read the absorbance of these solutions on a Bosch and Lomb 2500

Spectrophotometer using 550, 560, 565, 570 and 580 nm light settings and used linear regression to determine the standard curve parameters for each wavelength.

Shaking time. For field adaptation of the method, various times of wrist shaking were compared using soils from eight cover crop test strips in each of two adjacent Maryland farm fields. The samples of Myersville silt loam soil (pH 6.1) were collected in spring after a winter with either bare soil or rye (*Secale cereale* L.) cover. Both fields were cropped to corn, wheat (*Triticum aestivum* L.) and double-crop soybean [*Glycine max* (L.) Merr.] using no-till management, but the farmer judged one field to have higher soil quality than the other, based on past productivity.

An aliquot of 20.0 ml of 0.02 *M* $KMnO_4$ was added to 50 ml graduated propylene tubes and followed by a 5 ml scoop of air-dried soil (equivalent to 4.9 ± 0.3 g oven-dry soil). The soil–$KMnO_4$ mixture was wrist-shaken vigorously for 1, 2, 4 or 15 minutes, and then was allowed to stand for 10 minutes. Using a 1 ml graduated disposable bulb pipette, 0.50 ml of the aliquot was taken from the upper 1 cm depth and added to approximately 45 ml distilled water in another set of polypropylene tubes. To wash out the residual $KMnO_4$ solution in the pipette, it was filled and emptied three times with the diluted solution, returning the washing solution to the same tube from which it had come. After making to volume up to the 50 ml mark, the tube was capped and shaken to mix, and then about 15 ml of the diluted solution was poured into an optically calibrated glass vial (designed for the colorimeter used) and the light absorption measured by a 550 nm fixed wavelength palm-top Hach® 'generic' colorimeter. The results were subjected to ANOVA and the calculated amounts of oxidizable soil C, standard errors and *F*-values for the difference between fields were compared for the different shake times.

Supernatant clarification. The use of a salt (0.1 *M* $CaCl_2$) to stimulate soil flocculation and rapid settling in the soil–KMnO4 suspension was evaluated as an alternative to the centrifugation (3000 rpm for 5 min) and filtration required by the Blair et al. (1995) method. Three concentrations of $KMnO_4$ (0.005, 0.01 and 0.025 *M*) were shaken, as described above, with four Maryland soils (Hapludults with total organic C contents of 6–33 g kg^{-1} and clay contents of 125–305 g kg^{-1}). One set of subsamples was shaken in $KMnO_4$ solutions made in distilled water and a second set was shaken in the same concentrations of $KMnO_4$ made up in 0.1 *M* $CaCl_2$. The samples shaken in the pure $KMnO_4$ solutions were then centrifuged at 3000 rpm for 5 min and filtered through glass wool (as per Blair et al., 1995) while the samples shaken with $KMnO_4$ made up in 0.1 *M* $CaCl_2$ were not centrifuged or filtered, but were allowed to stand for 10 minutes. Otherwise, the procedures for the two sets of subsamples were as described above.

Dryness of soil samples. Sandy loam and clay loam soils collected from replicated experiments in Virginia and Maryland were analyzed as field-moist, after spreading in a thin layer in the sun to dry for 15, 30 or 60 min, or after air drying indoors for 24 h. The soil samples were then shaken for 2 min with 0.025 *M* $KMnO_4$ made up in 0.1 *M* $CaCl_2$ and analyzed as above.

Fine grinding of soil prior to analysis. Air-dried soil samples previously sieved to pass a 2 mm mesh were crushed with a mortar and pestle to <0.1 mm. Uncrushed <2 mm sieved soils and crushed <0.1 mm subsamples were then shaken with 0.02 *M* $KMnO_4$ for 2 min and analyses made as described above.

Repeatability and comparability of laboratory and field-kit protocols

Comparability of laboratory and field kit. Fifty-nine air-dried, sieved (<2 mm) soil samples from Maryland, New Jersey and North Dakota were analyzed by both the laboratory version of the proposed method (5.0 g soil in 20.0 ml of 0.02 *M* $KMnO_4$ solution dispensed with an automatic pipette, 2 min mechanical orbital shake time, centrifugation, absorbance read on Bosch and Lomb 2500 spectrophotometer set to 550 nm) and the field-kit version of the proposed method (5 g of soil, wrist-shaken for 2 min in 20 ml of 0.02 *M* $KMnO_4$ and 0.1 *M* $CaCl_2$ dispensed with a disposable 1 ml graduated bulb pipette, no centrifugation, and absorbance measured with single wavelength (550 nm) palm-top Hach® colorimeter). Linear regression was used to compare the two versions of the proposed method. In order to evaluate the coefficient of variation (CV) of the two protocols, three replicate analyses by each protocol were carried out on four samples of an Aura sandy loam from New Jersey. The four fields were sampled either in the fifth year of continuous crop production without any organic amendments, or in the first, second or third year of a hay in a hay/hay/hay/rye–vetch (*Vicia villosa*, Roth)/vegetables rotation with 10–15 Mg ha^{-1} of dry tree leaves plowed in before sowing the grass hay.

Laboratory sample exchange to evaluate repeatability of proposed field-kit method. To evaluate the consistency of the proposed method, nine air-dried, sieved (<2 mm) soil samples were obtained from the upper 15 cm of the no-till (NT), conventionally plow tilled (CT) and natural prairie plots in three replications of an experiment at Mandan, ND on a Wilton silt loam (Pachic Haplustolls). The tillage treatments had been in place for 17 years, and were confounded with cropping sequence. The CT treatment was under a spring wheat–fallow sequence, and the NT treatment was under a spring wheat–winter wheat–sunflower (*Helianthus annuus*) sequence. Subsamples of these soils were sent from North Dakota to Maryland. They were analyzed for active C by the proposed field-kit method (as described previously) in both the NRSC laboratory at Mandan and in the first author's laboratory in Maryland. These were the first samples ever run by the method in the Mandan lab. Results from the two labs were compared using linear regression.

Analysis of related soil quality properties and crop productivity

In addition to their analysis using the various $KMnO_4$-reactive C procedural variations described above, subsets of soils were also analyzed for total organic C [by LECO dry combustion or by wet acid chromate oxidation (Islam and Weil, 1998b)] and selected soil-quality properties that are thought to be related to active-fraction soil C. These were basal respiration (Islam and Weil, 2000), substrate-induced respiration (van de Werf and Verstrate, 1987), microbial biomass C (Islam and Weil, 1998a), anthrone-reactive C after microwaving [a measure of active C (Islam and Weil, 1997)], and aggregate stability [stability of 1–4 mm macroaggregates by a modification of Kemper and Rosenau (1986)]. Sets of diverse soil samples were used to investigate the relationships between 0.02 *M* $KMnO_4$-oxidizable active C and the just-listed soil-quality parameters by linear regression analysis (after analyzing the corresponding scatter plots to check for absence of curvilinear relationships).

A set of 18 samples from paired farm fields in Maryland, Pennsylvania and Virginia were used to evaluate the degree to which the various measures of soil C described above were able to distinguish (by paired *t*–test) between soils judged by farmers to be of higher or lower soil quality (Gruver, 1999). Soil samples from the conventional tillage and no-tillage treatments in the replicated experiment at Mandan, ND, described above, were compared by ANOVA to evaluate the relative ability of the proposed active C method and total organic C to detect a significant effect of management.

Corn biomass and grain yields were estimated by hand harvesting and weighing on 36 sampling plots (4 m × 2 m) in farm fields in the Lavanderos region in central Honduras. The relationships between soil C parameters and crop yields were investigated by linear regression techniques. SYSTAT version 9.0 (SPSS Inc., 1999) was used for all statistical analyses.

Results and Discussion

Effect of $KMnO_4$ solution molarity

When air-dry soil was reacted with 20 ml of $KMnO_4$ solution, increasing the concentration of the $KMnO_4$ solution from 0.005 to 0.05 *M* increased the amount of soil C oxidized, but there was little additional soil C oxidized when the concentration of the reacting solution was further increased to 0.1 *M* (Fig. 1). When the $KMnO_4$ concentration was increased beyond 0.1 *M* [to the 0.333 *M* of the Blair et al. (1995) method], the resulting solutions were too dark in color for absorbance readings to be obtained using the palm-top colorimeter proposed for the field-kit method. Increasing the $KMnO_4$ solution concentration beyond 0.025 *M* resulted in greater standard errors in the measurements and reduced ability of ANOVA to distinguish statistically between the two management

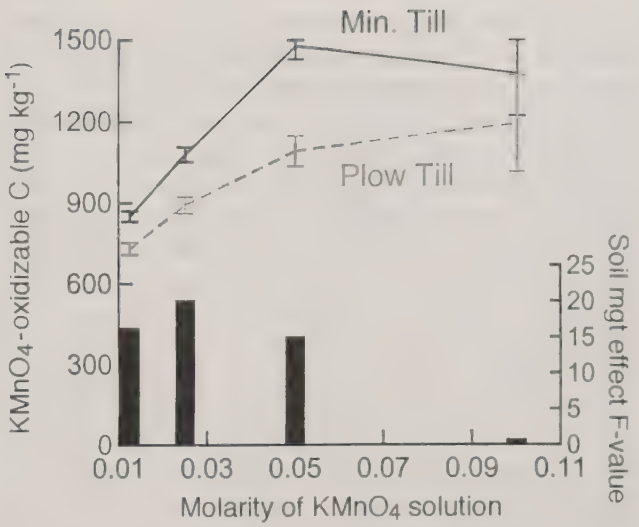

Figure 1. Effect of potassium permanganate concentration on the amount of soil C oxidized and on the ability of the oxidized C fraction to distinguish between soil management (tillage) treatments applied to a replicated experiment in Pennsylvania. Means and SE are shown for the C measurements. ANOVA *F*-values for soil management treatment effect are shown in the bar graph. Except for the solution concentration, the proposed field-kit protocol was followed.

treatments that had been imposed on the soils for 15 years in a replicated field plot experiment. The greatest treatment effect *F*-value was obtained with the 0.025 *M* $KMnO_4$ solution. In later studies using other soils (data not shown) we found that a concentration of 0.02 *M* was necessary to assure that readings could be obtained using the field-kit colorimeter for soils with essentially no organic matter. In these later studies, lower concentrations ($\leq$0.01 *M*) gave erratic results when soils were very high in organic matter (>5%) because all the $KMnO_4$ was consumed in the reaction, leaving no quantitative amount to be determined by absorbance. Therefore, a $KMnO_4$ solution concentration of 0.02 *M* was adopted as most suitable for the proposed active C method.

Optimal absorption wavelength

The standard curves prepared with zero, 0.005, 0.010 and 0.020 *M* $KMnO_4$ solutions exhibited excellent linearity ($R^2 > 0.99$) regardless of the wavelength of light used to read absorbance. However, the regression lines for the standard curve varied with the different wavelengths used. If the standard curve is described by the equation for a straight line (molarity = $a + b \times$ absorbance), a lower slope (b) will facilitate the detection of small differences in active soil C that result in small changes in the $KMnO_4$ solution concentration and light absorbance. The standard curve slope using 550 nm light was significantly lower (0.039) than the slopes using the longer wavelengths (0.061, 0.062, 0.073 and 0.108 for 560, 565, 570 and 580 nm light).

Averaged across the molar concentrations of the $KMnO_4$ solutions, the absorption measured at 550 nm gave consistently higher readings (data not shown) and higher or equal R^2 than absorption of standard solutions measured at other wavelengths. The 550 nm wavelength was adopted for use in the proposed active C method because the use of this wavelength always resulted in a standard curve with the lowest slope and highest regression coefficient. Use of 550 nm, rather the 665 nm specified by Blair et al. (1995), should enhance the precision with which the amount of soil C oxidized may be determined. Fortunately, we were able to find a single-wavelength generic (not preprogrammed for a specific analysis) hand-held colorimeter available for 550 nm absorbance. Light of wavelength 550 nm was used for all determinations subsequently reported in this paper, and the palm-top colorimeter was used for all subsequent results described as using the 'field-kit method'. It should be noted that when the values for the molarity of the $KMnO_4$ remaining unreacted are converted to mg soil C reacted, the curve so obtained has a negative slope, as the greater the amount of C reacted, the lower the absorbance.

Effect of shaking time

The effect of shaking time on the amount of C oxidized by a 0.02 *M* $KMnO_4$ solution was investigated using soil samples from two adjacent fields on a Maryland grain farm. The farmer reported that, although the fields were alike with regard to soil type and management history, one field consistently produced greater crop yields than the other. The amount of C oxidized increased with the time the soil was shaken in the solution (Fig. 2). A shake time of 15 minutes (as per the method of Blair et al., 1995) was also tried (data not shown). In addition to being an onerously long time for hand shaking in a field-kit method, the 15-min shake time resulted in all the 0.02 *M* $KMnO_4$ being consumed for most soils, so no absorbance reading could be made. Furthermore, no results could be obtained from a treatment that used a 15-min shake time divided into two 7.5-min shaking periods with a 3-min standing time between shaking periods. Immediately on re-shaking, the permanganate purple color of the mixture suddenly disappeared. We subsequently observed that this sudden color disappearance usually occurred if a sample was disturbed after having been shaken and allowed to settle.

With 1-, 2- or 4-min shake times, the 0.02 *M* $KMnO_4$-reactive C was significantly higher in the field reported to be consistently higher yielding. However, the ANOVA *F*-ratios for the effect of field were 13, 14 and 6 for the 1-, 2- and 4-min shake times. The SE of the active C measurements did not change between 1 and 2 min of shake time, but did increase with longer shake time (Fig. 2). We therefore adopted a 2-min shake time for the proposed active C method. Because of the factors just discussed, the duration of shaking should be precisely timed and any further disturbance of the mixture after settling carefully avoided.

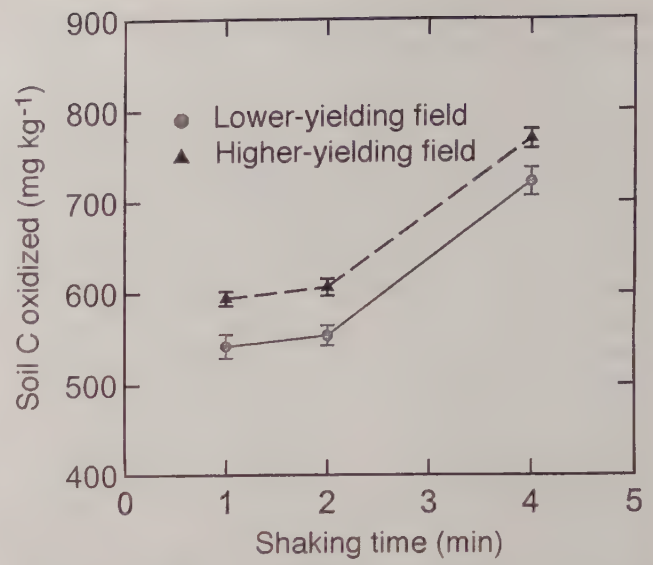

Figure 2. The effect of shaking time on the amount of C oxidized by a 0.02 *M* $KMnO_4$ solution in soil samples from two adjacent farm fields in Maryland with differing yield histories reported by the farmer. The data are means of eight samples from each field taken in spring. Bars indicate the standard errors of the means.

Table 1. Active soil C (mg kg^{-1}), as measured by oxidation with several concentrations of $KMnO_4$, as influenced by the use of flocculation with 0.1 *M* $CaCl_2$ or centrifugation to clear the supernatant solution. Means of four soils.

Clarification treatments	$KMnO_4$ concentration			
	0.005 *M*	0.01 *M*	0.025 *M*	*F*-ratio
Centrifugation	620	1110	1780	1900***
0.1 *M* $CaCl_2$	620	1130	1870	890***
t–test	ns	ns	ns	

*** Significant at the 0.001 level.

Method of supernatant clarification

The amount of oxidizable C measured in four soils did not vary significantly between subsamples using centrifugation/filtration to clear the supernatant (Blair et al., 1995) and subsamples for which the $KMnO_4$-reacting solutions were made up in 0.1 *M* $CaCl_2$. Increasing the ionic strength of a solution, especially with a divalent ion such as Ca^{2+}, is expected to stimulate the flocculation of soil particles and therefore hasten their settling out of suspension (Brady and Weil, 2002, p. 427–428). Using 0.1 *M* $CaCl_2$ in the $KMnO_4$ solution resulted in a clear supernatant solution within a few minutes of standing after shaking. For all three concentrations of $KMnO_4$ tried, there was no difference in the absorbance readings for centrifuged $KMnO_4$ without $CaCl_2$ compared to simply allowing 5 minutes for settling with 0.1 *M* $CaCl_2$ (Table 1). Therefore, use of a 0.02 *M*

$KMnO_4$ made with 0.1 *M* $CaCl_2$ was adopted for the field-kit protocol in the proposed active C method.

Soil drying

Although air drying and sieving is standard procedure for most laboratory measurements of soil C, we compared different degrees of soil drying in an attempt to simplify and streamline the protocol for the field-kit version of the proposed active C method. The effect of soil sample drying time on C oxidized by a 0.02 *M* $KMnO_4$ solution is shown in Figure 3. Means and SE are shown for samples from various treatment plots in field experiments on two soils.

Increased soil dryness increased the amount of C reacting with the $KMnO_4$ solution, probably because of the higher redox potential that usually accompanies increased dryness (Bartlett and James, 1993), although no attempt was made to measure soil Eh. The difference in soil water content among the drying treatments was negligible in terms of affecting dilution of the reagent (<1 ml compared to 20 ml of reagent), especially since the greatest oxidation differences occurred among the drier treatments. Readings on fresh, moist soils were more variable than on dried soils, but even moderate drying (spreading soil in a thin layer for 15–30 min in the sun) resulted in good repeatability and discrimination between soil management treatments (data not shown). We concluded that long-term air drying is the preferred method of sample preparation for maximum accuracy, but that, for comparisons in the field, 15 min of drying in the sun should be adequate if a black tray is used. Of course, ambient humidity and temperature can affect the degree of soil dryness achieved, and should be taken into account when comparing soils dried under differing conditions. The main consideration is that all samples being compared should be of equal dryness, since the dryness of the soil does influence the results.

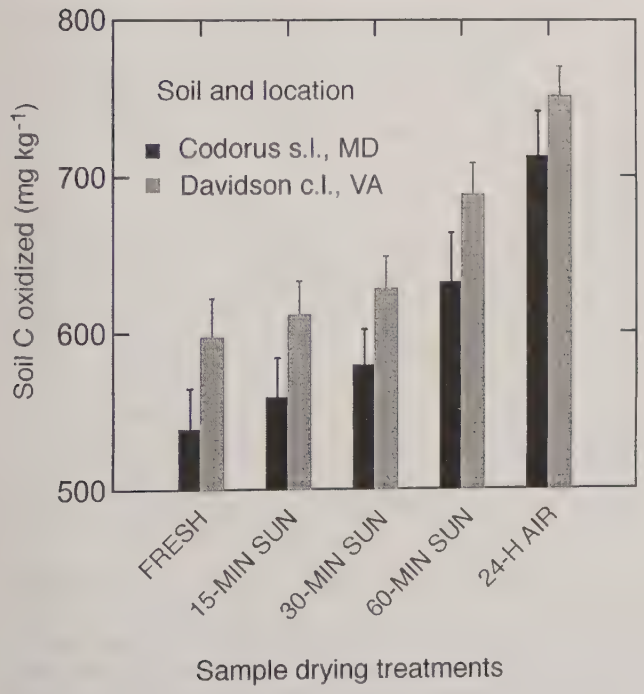

Figure 3. Effect of sample drying time on C oxidized by 0.02 *M* $KMnO_4$ solution for two soils. Soil moisture content was near field capacity at time of sampling. Air temperature was 25°C in full sun. Means and SE for each soil are shown. Samples were collected from four blocks of two treatments on each soil.

Soil grinding

Some degree of soil grinding or aggregate crushing is normal practice in preparing soil samples for most laboratory analyses (Wollum, 1994). The main purpose of grinding and sieving soils prior to analysis is to assist in homogenizing the sample, so a representative subsample can be taken. To assure an unbiased representation of the soil sample, the small subsample that is actually subjected to the analysis should contain a large number (>1000) of soil particles or aggregates. Including a large number of individual particles in a subsample is made possible either by using a large sample size or by reducing the size of the individual particles. Many procedures for soil C analysis call for the soil to be ground to pass a 0.5 mm sieve because of the small (<1 g) sample size used. Aside from these considerations of subsampling error, crushing and sieving a soil sample may affect the determination of soil C because the process may expose some C, especially particulate organic matter that was occluded inside the larger soil aggregates.

Table 2 shows that crushing aggregates from a maximum diameter of 2 mm to a maximum diameter of 0.1 mm increased the amount of active C by 7–12%, as determined by reaction with 0.025 *M* $KMnO_4$ (this study was done before 0.02 *M* was chosen as the $KMnO_4$ concentration in

Table 2. Effect of soil grinding on oxidation of organic C by neutral 0.025 *M* $KMnO_4$ in soil samples from adjacent plots with differential management histories. Means of eight on-farm plots on a Glenelg silt loam (Typic Hapludults) in Lancaster Co., PA.

	Oxidizable soil C (mg kg^{-1})		
Years in no-till management	Uncrushed aggregates (<2 mm)	Crushed aggregates (<0.1 mm)	ANOVA *F*-ratio for aggregate size
3	1780	1980	12.42*
17	2700	2910	20.65*
ANOVA *F*-ratio for management	285***	356***	

* Indicates that the effect of crushing was significant at the 0.05 level.

*** Indicates that the effect of management history was significant at the 0.001 level.

the proposed method). In addition, the precision of the determination improved slightly when using crushed soils, as indicated by the greater ANOVA *F*-value for management. However, the *F*-values for both crushed and uncrushed soils were highly significant, indicating a high level of consistency in these particular field plots as well as in the active C analysis. For the laboratory protocol of the proposed active C method, we adopted the use of <0.5 mm ground and sieved samples. However, for a field-kit protocol, such fine sieving would be impractical, and crumbling finely by hand is called for, with the caution that differences in aggregate strength may influence the degree to which aggregates are disrupted by this sample preparation technique. In addition, in the field we found it more convenient to measure out analytical subsamples using a standard 5 ml scoop instead of a balance. Although this method of subsampling based on volume has it merits, a high degree of reproducibility is not one of them. Nevertheless, we found that for samples of similar textures, crumbling soil and leveling it off in a 5 ml scoop measured out 4.86 g of soil with a coefficient of variation of 6%. We therefore consider the 5 ml scoop to be an acceptable alternative for the use of a portable balance weighing to 0.1 g for work in the field when the objective is to obtain comparative values among similar soils.

Comparison of results using laboratory and field-kit protocols

We have developed two versions of the proposed active C method, one for precise work in the laboratory (referred to herein as the laboratory protocol), and one for use in a field setting, where some precision may be sacrificed for simplicity, speed, convenience and low cost. To compare the results from these two protocols, we subjected duplicate subsamples of 59 soils to active C analysis using both versions of the proposed method. Except where indicated otherwise, we used air-dried (>24 h), sieved soils for both protocols, and weighed out the subsample for analysis using a portable balance. The field-kit protocol differed from the laboratory protocol in these ways:

1. the use of a Hach® palm-top single-wavelength colorimeter (550 nm) instead of a laboratory spectrophotometer;
2. the inclusion of 0.1 *M* $CaCl_2$ in the 0.02 *M* $KMnO_4$ solution and a 5-min settling period instead of using centrifugation to enhance settling and clarify the supernatant;
3. the use of 1 ml graduated disposable bulb pipettes instead of laboratory-grade pipettes to measure out volumes of the reacting solution and supernatant aliquots; and
4. the use of hand shaking instead of a mechanical orbital shaker.

As illustrated by the data in Figure 4, results from the two protocols of the proposed active C method were highly correlated ($R^2 = 0.98$) over a wide range of soils. Also shown in Figure 4 are data for 16 soils sampled from southern Brazil and analyzed using a prototype portable kit in the field. These analyses were performed using a 5 ml scoop to measure hand-crumbled soil that had been only partially air-dried under cool (8–12°C), cloudy, humid winter conditions. The laboratory determinations were performed on air-dried, sieved subsamples 1 month after transporting the samples from Brazil to Maryland. The added variability due to inconsistent drying and imprecise subsampling probably account for the greater degree of discrepancy between the laboratory and field determinations in this set of samples.

Repeatability of proposed method

Given that the proposed active C method is designed to measure an operationally defined fraction of soil C, there may be no good way to estimate the *accuracy* of the method. However, we estimated the precision and repeatability of the method in several ways. Table 3 shows the results for soils from four New Jersey farm fields, either in the fifth year of continuous crop production without organic amendments, or in the first, second or fourth year of hay in a leaves/hay/hay/hay/rye–vetch/vegetables rotation. With one unexplained exception, the laboratory protocol and the field protocols gave very similar CVs, in the range of 1–4%, certainly within an acceptable range for most soil C analyses. Based on the LSD values shown in Table 3, both

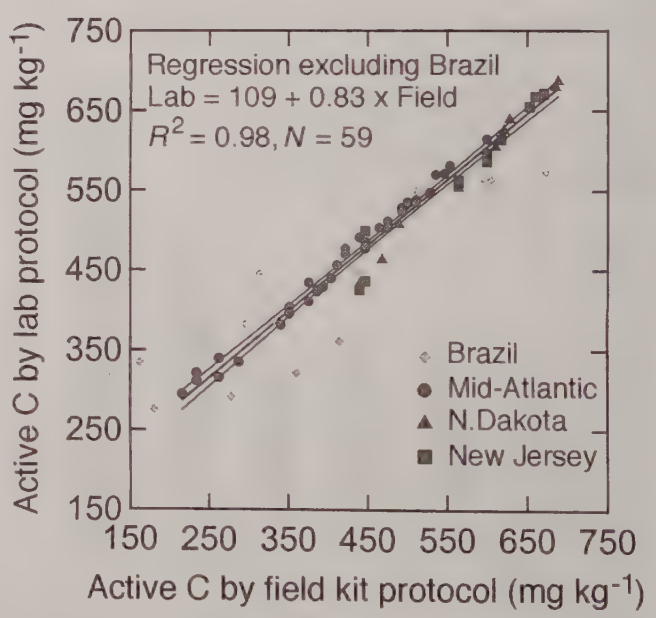

Figure 4. A comparison between the laboratory and field-kit protocols for the proposed active C method. All determinations, except those for the Brazil field-kit protocol, used sieved, air-dry soil samples. The Brazil field-kit determinations were made under poor conditions for soil drying (cold, damp weather), using a scoop to measure hand-crumbled soil. The regression comparing these Brazil field determinations to the laboratory protocol was: Laboratory = 158 + 0.7 × field, $R^2 = 0.76$, $N = 16$.

versions of the method distinguished between soils that were in the hay and leaves rotation and those that were not.

The repeatability of the proposed method was also investigated through a sample exchange in which nine well-homogenized subsamples of air-dried soil from a replicated field experiment in North Dakota were analyzed in laboratories at the University of Maryland and the USDA/NRCS in Mandan, ND. The Maryland laboratory is that of the senior author and the personnel there were already well experienced with the method. The personnel at the North Dakota laboratory were unfamiliar with the procedure prior to the time these samples were analyzed. The field-kit protocol was used, as described previously. The soil samples came from conventionally tilled cropped plots, no-till managed cropped plots, and lightly grazed native prairie plots. Figure 5 shows that the two labs produced very similar active C results.

Table 3. Variance in 0.02 *M* $KMnO_4$-oxidizable C results using the laboratory and field-kit protocols to measure active C in 0–15 cm samples of an Aura sandy loam (coarse-loamy, siliceous, semiactive, mesic Typic Fragiudults) from four New Jersey farm fields with different organic matter management histories. Means and CVs for triplicate determinations.

	Laboratory method		Field-kit method	
Experimental treatments	**Mean (mg kg^{-1})**	**CV (%)**	**Mean (mg kg^{-1})**	**CV (%)**
Continuous cropping	453.6	8.8	444.6	0.9
H H V L H[1]	600.5	2.1	605.7	1.7
H V L H H	569.8	2.5	576.1	3.6
V L H H H	664.8	1.3	661.4	1.4
LSD ($P<0.001$)	93.1		54.4	

[1] H = hay, L = fallowed with ~15 Mg ha^{-1} municipal tree leaves incorporated, V = vegetables. Underlined last symbol on the right indicates rotation phase when sampled.

Usefulness of the proposed active C method for assessing soil quality

A repeatable, easy-to-use method for estimating active soil C will be helpful in assessing soil quality only to the extent that the C fraction measured is sensitive to changes in soil quality and allows the investigator to detect these changes consistently. Furthermore, to be meaningful as an estimate of the size of the active C pool, the results of the proposed method should exhibit significant relationships with soil microbial processes and other soil-quality indicators. Here we present data to show that the proposed method is both more sensitive to management-induced soil

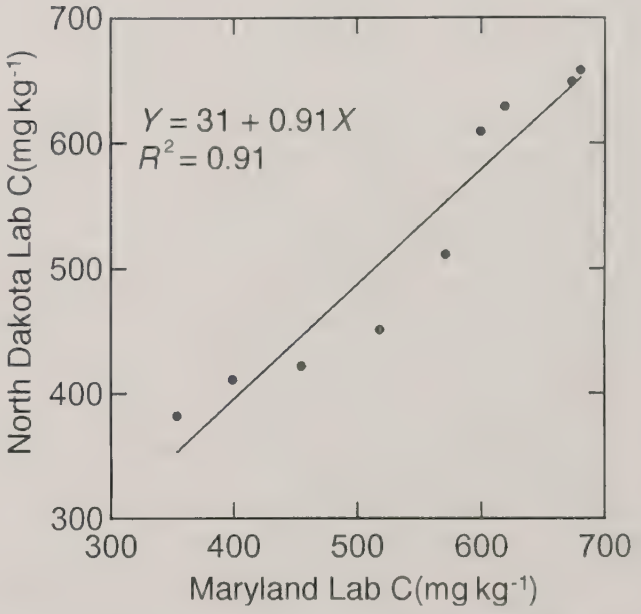

Figure 5. A comparison of active C measured by two different labs using subsamples from the same nine North Dakota soil samples. The protocol used was that of the field-kit method described herein. The North Dakota laboratory had no prior experience with the method.

Table 4. The relationship between soil quality (SQ) rating by farmers and selected fractions of soil carbon as determined by various methods in 19 pairs of soils in the mid-Atlantic region.

	Carbon conc. (mg kg^{-1})[1]		Paired *t*-test	
Soil C analysis method	**Higher SQ**	**Lower SQ**	***t*-value**	**Probability**
0.02 *M* $KMnO_4$ oxidizable C, field-kit version	455.6	384.7	6.25	0.000007
0.02 *M* $KMnO_4$ oxidizable C, laboratory version	493.2	430.2	6.20	0.000008
Total organic C (LECO)	24,900.0	17,300.0	5.02	0.0001
0.333 *M* $KMnO_4$ oxidizable C (Blair et al., 1995)	5450.0	3960.0	4.63	0.0002
Anthrone-sulfuric acid reactive carbohydrate C	97.2	78.1	3.65	0.002
p–Hydroxybenzoic acid hydrazide reactive C	31.1	26.8	1.83	0.08

[1] Pairs of similar soils judged by farmers as being higher or lower in soil quality, based on the relative yield histories, workability, erodibility and other farmer observations (Gruver, 1999).

changes and more closely related to biologically mediated soil properties than are other measures of soil C, including total soil organic C and C oxidizable by the 0.333 *M* $KMnO_4$ method of Blair et al. (1995).

Management effects on active C

Farmers in several mid-Atlantic States identified pairs of fields that, in their experience, exhibited contrasting soil quality, usually because of past management (Gruver, 1999). The soils in each pair were very similar pedologically and were generally mapped as the same or similar soil series and phase. Table 4 shows how six measures of soil organic C differed between the soils grouped by farmers as higher and lower in soil quality. The sensitivity of the C parameter to the perceived differences in soil quality can be judged by the *t*-value, a statistic indicating with how much certainty the two populations of soils were different by a paired *t*–test. Four of the five C parameters differed significantly between the lower and higher soil-quality fields. However, the *t*-values for the laboratory and field-kit protocols of the proposed active C method were greater that those for total organic C or 0.333 *M* $KMnO_4$-oxidizable C by the Blair et al. (1995) method. Therefore, even though the latter two measures exhibited greater relative differences between the lower- and higher-quality soil groups, the proposed active C method exhibited a more consistent difference between the two soil-quality categories.

Figure 6 presents two measures of soil organic C found in experimental plots subjected to either conventional tillage or no-tillage management in a wheat-based rotation at Mandan, North Dakota. Based on the *F*-values from analysis of variance, the two treatments differed significantly with regard to active C as measured by the proposed method (ANOVA *F*-ratio = 34), but were not significantly different in total organic C (ANOVA *F*-ratio = 4). Such results are in agreement with the theoretical expectation and common observation that the active C pool is more rapidly increased or decreased by changes in soil management and cropping systems than is the mainly recalcitrant total soil organic C pool (Paustian et al., 1997).

Relationship between active C and other soil quality indicators

Table 5 shows the correlations among five soil organic C fractions and four microbial soil properties in surface soil samples collected from 18 mid-Atlantic farm fields representing a wide range of textures, organic matter contents and cropping systems. Active C by the proposed 0.02 *M* $KMnO_4$ method was more closely correlated than was the Blair et al. (1995) method with each of the four measures of microbial activity (substrate-induced respiration, basal respiration, microbial biomass and soluble carbohydrates). On the other hand, the Blair et al. (1995) method gave results more closely correlated to total organic C than those from the proposed method. Both methods for permanganate-oxidizable C gave results that were weakly

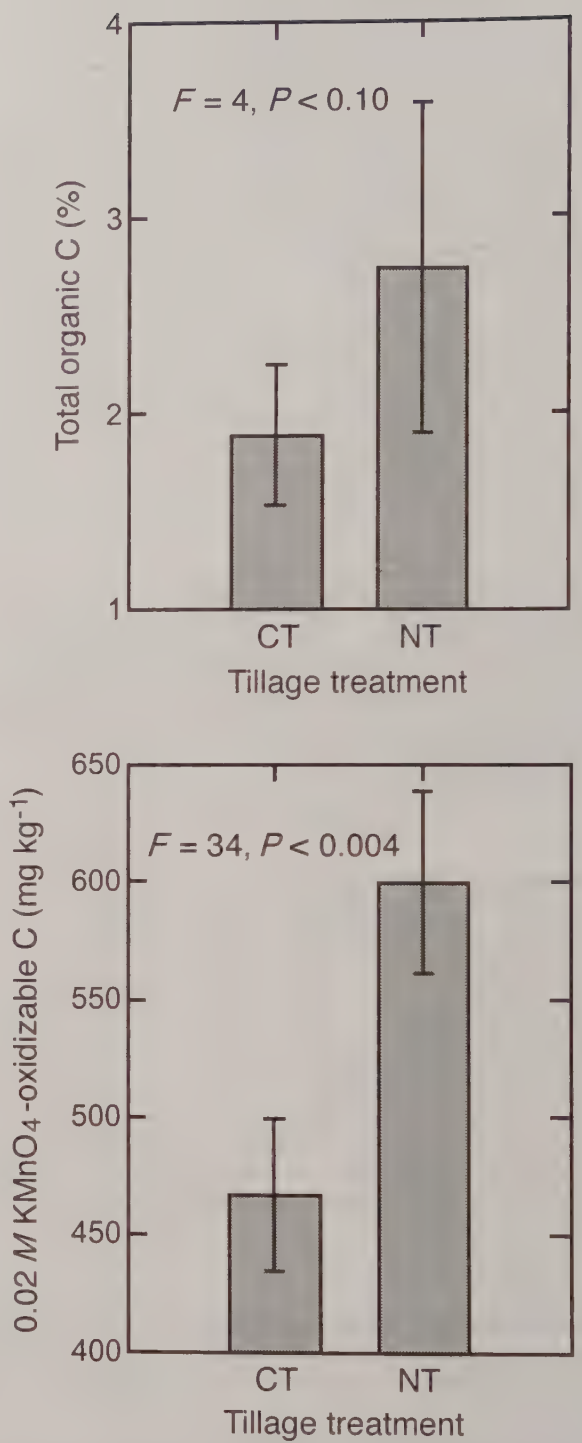

Figure 6. Comparative sensitivity of total organic C and active C by the proposed method in distinguishing between long-term tillage treatments (CT = conventional plow tillage, NT = no-till) in a replicated wheat-based rotation experiment at Mandan, ND. The total C levels were not significantly different between the treatments, but a highly significant difference was observed in the active C levels (*F* ratio and probability from ANOVA shown). The soil was a Wilton silt loam (fine-silty, mixed, superactive frigid Pachic Haplustolls).

Table 5. Linear correlations (r) between selected measures of microbial activity and various fractions of soil C in samples from 18 mid-Atlantic farm fields.

	Total organic C[1]	0.5 M K_2SO_4 extractable C	Soluble carbohydrate C[2]	0.333 M $KMnO_4$ oxidizable C[3]	0.02 M $KMnO_4$ oxidizable C[4]
Substrate-induced resp.	0.55*	0.73***	0.48*	0.60**	0.74***[4]
Basal respiration	0.45^{NS}	0.07^{NS}	0.56*	0.46^{NS}	0.56*[4]
Microbial biomass C	0.60**	0.37^{NS}	0.96***	0.79***	0.85***[4]
Soluble carbohydrate C[3]	0.56*	0.33^{NS}	1.00	0.68**	0.84***[4]
Total organic C[1]	1.00	0.58**	0.56*	0.77***	0.69**[4]
K_2SO_4-extractable C	0.58**	1.00	0.30^{NS}	0.51*	0.51*[4]

[1] By LECO high temperature combustion.
[2] Glucose equivalents reactive with anthrone after microwave irradiation.
[3] By method of Blair et al. (1995).
[4] By proposed active C method, laboratory protocol.
*, **, *** Indicate significance at the 0.05, 0.01 and 0.001 probability levels.
^{NS} indicates no significant correlation at the 0.05 probability level.

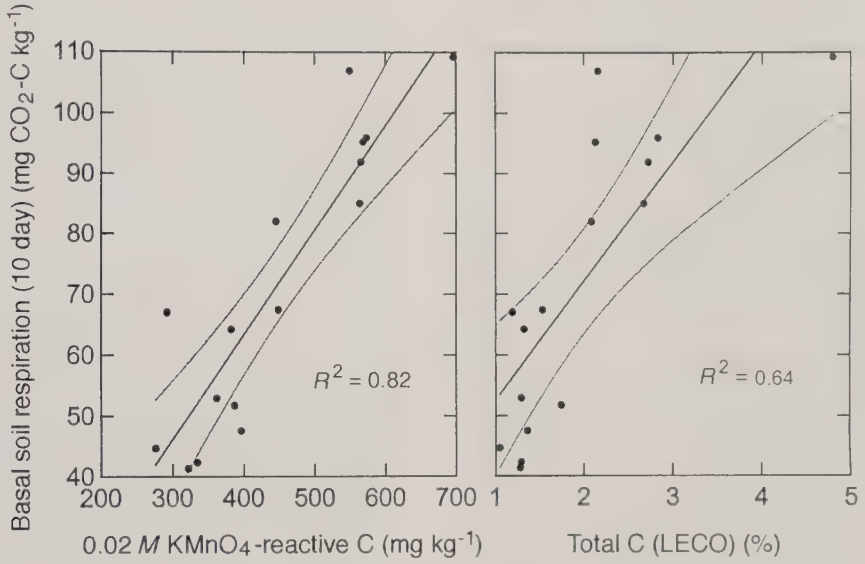

Figure 7. The relationships between basal microbial respiration and two fractions of soil organic C, total and active (as determined by the laboratory protocol of the proposed method) in 16 soil samples from farm fields in southern Brazil.

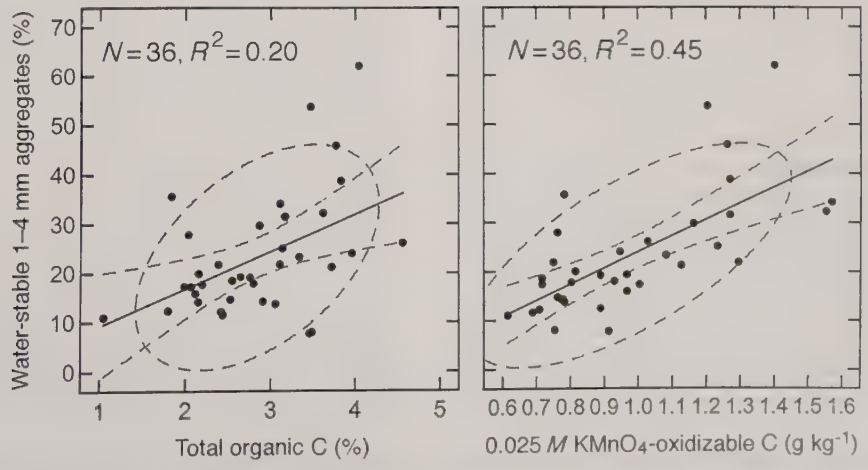

Figure 8. The relationships between the stability of macroaggregates and the content of active C or total organic C in soils from hillside farmers' fields in the Lavanderos region of Honduras. The active C in these samples was determined using the laboratory protocol of the proposed method, but with 0.025 M rather than 0.02 M $KMnO_4$ solution.

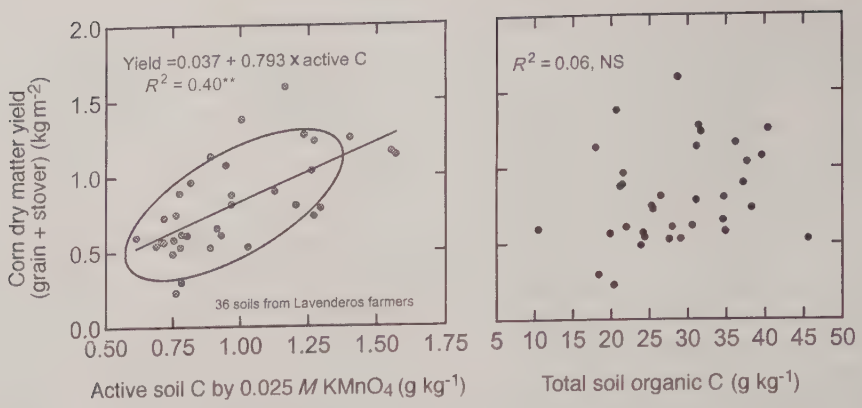
Yield =0.037 + 0.793 x active C
R^2 = 0.40**
36 soils from Lavenderos farmers
Corn dry matter yield (grain + stover) (kg m^{-2})
Active soil C by 0.025 M KMnO4 (g kg^{-1})
R^2 = 0.06, NS
Total soil organic C (g kg^{-1})

Figure 9. The relationship between above-ground dry matter yield of corn (*Zea mays* L.) in 36 on-farm plots in Lavanderos Honduras and the soil content of active C (left) or total C (right).

and equally correlated ($r = 0.51$) with soluble C (by K_2SO_4 extraction). Soluble C was not correlated to any of the microbial activity measures, except substrate-induced respiration. Soluble carbohydrates were very closely correlated ($r = 0.96$) to microbial biomass C. This is not surprising as the carbohydrates were measured after the same microwave irradiation treatment applied to lyse cells in determining microbial biomass.

In several other sets of soils investigated, active carbon by the proposed method was consistently more closely related to other soil-quality properties than was total organic C (Figs 7–9). For example, for the 16 soils sampled from farms in southern Brazil, basal respiration was more closely related to active C than to total C (Fig. 7). For a set of 36 soil samples from hillside farms in central Honduras, the aggregate stability varied more closely with active C than with total organic C (Fig. 8). On these same on-farm plots in Honduras, active C, but not total C, exhibited a significant linear relationship with the crop biomass produced (Fig. 9).

Conclusions

We have shown that a dilute (0.02 *M*) solution of slightly alkaline $KMnO_4$ can be used to react with diverse soils to estimate a biologically active soil C pool. We developed a highly simplified method in which dilute $KMnO_4$ reacts with the most readily oxidizable (active) forms of soil C, converting Mn(VII) to Mn(II), and proportionally lowering absorbance of 550 nm light. A 0.02 *M* $KMnO_4$ solution concentration, air-dry soil (or 15 min of sun drying in the field), and 2 min of shaking provided optimum ease, consistency and sensitivity of results to management effects using laboratory equipment or a field kit with a palm-size colorimeter. Addition of 0.1 *M* $CaCl_2$ to the permanganate reagent provided for rapid settling of the soil after shaking, eliminating the need for centrifugation or filtration in the field kit.

Results from the laboratory and field kit were very similar ($R^2 = 0.98$), as were those from an inter-laboratory sample exchange ($R^2 = 0.91$). Compared to total organic C, the active soil C measured by the new procedure was more sensitive to management effects, and more closely related to soil productivity and biologically mediated soil properties, such as respiration, microbial biomass and aggregation. The new procedure presents several distinct advantages over the 0.333 *M* $KMnO_4$ procedure of Blair et al. (1995). These include the dilute reagent which is easier to work with and less hazardous, the elimination of centrifugation and filtration steps, a simpler, streamlined protocol suitable for field as well as laboratory use, and measurement of a soil C fraction that is more closely related to microbial and soil-quality properties. Although we did not attempt to do this, it should be possible to use the new method in calculating a C management index such as that proposed by Blair et al (1995).

Based on the results just described, we assembled a field kit using a 0.02 *M* $KMnO_4$ solution made with 0.1 *M* $CaCl_2$; a palm-sized single (550 nm) wavelength spectrometer; plastic, screw-top, conical centrifuge tubes for hand-shaking; disposable 1.0 ml graduated bulb pipettes; and a 5 cm^3 soil scoop. The entire kit can fit into a 16 × 15 × 20 cm plastic carrying case and is suitable for use in the field.

The field kit has potential as a tool for farmer education in the field, as well as for soil-quality research. We suggest that it might be a suitable addition to the NRCS soil-quality test kit, as that kit currently includes no soil organic matter test. Current work is focusing on calibrating the new method for routine use in soil-testing programs to help advise on the need for improved soil organic matter management.

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Appendix

Field-kit method for $KMnO_4$-oxidizable C to estimate active organic carbon in soils[1]

Materials.

1. Stock solution: 0.2 *M* $KMnO_4$ in 1 *M* $CaCl_2$ (pH 7.2). Adjust pH to 7.2 using 0.1 *M* NaOH. This solution pH is important for maintaining stability of the stock solution for 3–6 months. The pH-adjusted 0.2 *M* $KMnO_4$ stock solution should be kept in a dark bottle.
2. Standard solutions: 0.005, 0.01 and 0.02 *M* $KMnO_4$ in 0.1 *M* $CaCl_2$. Make by adding 1.25, 2.50 or 5.00 ml of the 0.2 *M* $KMnO_4$ stock solution to respective centrifuge tubes and diluting to the 50 ml mark with distilled water.
3. Hand-held colorimeter (generic 550 nm colorimeter, Hach® Company, Boulder, CO).
4. Optically matched glass cuvettes; laboratory tissues for wiping cuvettes.
5. Plastic lab ware: nine graduated polypropylene conical centrifuge tubes (50 ml); two plastic disposable 1 ml graduated bulb pipettes, for stock and for dilute solutions; scoop (calibrated to 5 ml); plastic cup (50 ml); rack to hold centrifuge conical tubes in upright position.
6. Distilled water in sealable squeeze bottle.

Procedure.

Most conveniently carried out with batches of three samples.

1. If sampling moist soil in the field, take a small representative subsample of field-moist soil (approximately 20 g or five scoops), crumble gently and spread thinly on a piece of black paper to air-dry for 15 min (preferably in direct sunlight). Mix the crumbled soil two or three times during air-drying.
2. Using a disposable bulb pipette, place 2.0 ml of the 0.2 *M* $KMnO_4$ in a clean 50 ml graduated polypropylene conical centrifuge tube. Add distilled water to the 20 ml mark and cap the tube. Swirl the tube to mix the solution thoroughly. Add one level scoop (or weigh 5.0 g) of uniformly dry soil to the tube and cap it tightly.
3. Shake vigorously (about 100 strokes/min) for 2 min, and then stand the tube in a rack for 5–10 min to allow soil to settle. Protect the tube from direct sunlight. The $CaCl_2$ in the solution will cause the soil to flocculate and rapidly settle, clearing the upper portion of the solution.
4. The settling time may be used for making a standard curve as follows.

   (a) Fill a clean[2] glass cuvette with distilled water; wipe the outside of the vial with a tissue and place the vial in the colorimeter well. Put the cover in place and press the 'zero' button. After a few seconds, the LED should read '0.00'. Remove the cuvette.

   (b) Add about 45 ml of distilled water to a clean graduated centrifuge tube. Using the disposable bulb pipette, add 0.50 ml of the 0.005 *M* $KMnO_4$ standard solution to the tube, then fill and empty the pipette with the diluted solution several times to insure that all the solution is delivered. Then add distilled water to the 50 ml mark, cap and shake to mix. Pour about 15 ml of this diluted standard into a clean 20 ml glass cuvette; wipe the outside with a tissue and place in the colorimeter well. Put the cover in place and press the 'read' button. Record the absorbance displayed.

   (c) Repeat these steps (4b) using 0.50 ml of the 0.01 *M* and 0.02 *M* $KMnO_4$ standard solutions. Record the absorbance for each standard solution. Construct a standard curve with absorbance on the *x*-axis and concentration on the *y*-axis.
5. After measuring the absorbance of the standard solutions, add approximately 45 ml distilled water to a clean, graduated centrifuge tube. Use a clean bulb pipette to take 0.50 ml of liquid from the upper 1 cm of the soil–$KMnO_4$ suspension (avoid floating debris) and transfer this to the tube of distilled water. Wash out the residual $KMnO_4$ solution in the pipette by filling and emptying it three times with the diluted solution. Then add distilled water up to the 50 ml mark, cap, and shake. Pour about 15 ml of this diluted solution into a clean 20 ml glass cuvette. Wipe the outside of the cuvette with a tissue and place it in the colorimeter well. Put the cover in

place and press 'read'. Record the absorbance for the sample solution[3].

Calculation[4]. The bleaching of the purple $KMnO_4$ color (reduction in absorbance) is proportional to the amount of oxidizable C in soil. In other words, the greater the $KMnO_4$ color *loss* (the lower the absorbance reading), the greater the amount of oxidizable C in the soil. To estimate the amount of C oxidized, use the assumption of Blair et al. (1995) that 1 mol MnO_4 is consumed (reduced from Mn^{7+} to Mn^{2+}) in the oxidation of 0.75 mol (9000 mg) of C:

$$\text{Active C (mg kg}^{-1}) = [0.02\ \text{mol/l} - (a + b \times \text{absorbance})] \times (9000\ \text{mg C/mol}) \times (0.021\ \text{solution}/0.005\ \text{kg soil})$$

where 0.02 mol/l is the initial solution concentration, a is the intercept and b is the slope of the standard curve, 9000 is mg C (0.75 mol) oxidized by 1 mol of MnO_4 changing from Mn^{7+} to Mn^{2+}, 0.021 is the volume of $KMnO_4$ solution reacted, and 0.005 is the kg of soil used.

[1] To increase precision and convenience when working in a laboratory, precise weighing of 5.0 g air-dry, <1 mm sieved soil can be substituted for the 5 ml of crumbled soil, a horizontal shaker at 120 rpm can be used instead of hand shaking, a standard laboratory spectrophotometer set to read 550 nm light can be used in place of the portable colorimeter, and an auto-pipettor can be used instead of disposable bulb pipettes.

[2] If blank absorbance readings increase after 10–20 determinations, it may be necessary to clean the glass cuvette vials with 10% bleach solution to remove sorbed permanganate.

[3] If absorbance is <0.01, repeat steps 2, 3 and 5 using half as much soil (2.5 g) and adjust the soil weight accordingly in the calculation given below.

[4] For reference, typical absorbance readings obtained by the authors for the standard solutions using a HACH 550 nm colorimeter are: 0, 0.21, 0.44 and 0.84, which give the standard curve equation: conc. = –0.0005 + 0.0252 × abs. Therefore a typical calculation (within rounding error) for active C would be: active C (mg/kg) = [(0.02) – (–0.0005+0.0252 × Abs)] × 36000.

The natural and organic pork market: A sustainable niche for small-scale producers? A review and analysis of the evidence

W. Parker Wheatley

Abstract. *This study reviews the literature on consumer preferences and willingness to pay for pork produced through alternative methods, such as natural and organic production. It finds evidence suggesting that many consumers are willing to pay relatively high premiums for natural and organic pork. Furthermore, research is found which suggests that such premiums can be expected to persist into the foreseeable future. This study also investigates the degree to which such premiums are transmitted to pork producers and finds anecdotal evidence suggesting that natural and organic pork producers receive modest premiums as well as more stable pricing overall. This paper then discusses the marketing efforts needed and impediments to supplying the natural and organic markets for pork. The overall perspective provided by this paper is that natural and organic production may be viable alternatives to more capital-intensive production for many small-scale producers.*

Key words: consumer preferences, consumer willingness to pay, niche marketing, price premiums

Introduction

In the past decade, there has been a significant decline in the number of small-scale hog (*Sus scrofa*) farms in the US. In 2000, operations marketing fewer than 1000 animals produced 13.4 million fewer hogs than in 1994, a decrease of 80%. Production by these smaller operations accounted for 2% of all hogs in the market in 2000, representing a significant decrease from 1988, when production by such farms accounted for 32% of all hogs marketed (Lawrence and Grimes, 2001; Lawrence et al., 1998). Some researchers argue that these changes have resulted from economies of scale in production, in the sense that larger quantities of pork can be produced at lower costs by fewer and larger farms. Others argue that economies of scale are negligible for operations above 150 sows (Ginder, 1998).

Despite the debate over whether size matters in production, large pork producers have a greater ability to mobilize larger quantities of capital. This capacity for borrowing allows larger producers more flexibility in incorporating new technologies to meet the needs of traditional downstream clients. Smaller independent producers have difficulties in duplicating such capital-intensive modernization because of their limited ability to obtain financing at a reasonable cost. Complicating the situation for smaller independent producers is that vertical coordination and contracting have left traditional spot markets for pork somewhat thin and volatile. Consequently, smaller producers are facing adverse pressure from both the cost and the revenue sides of their operations. The 1998 events in the hog market indicate how these problems have most seriously affected smaller producers. While all producers were hurt by the adverse market conditions prevalent in 1998, smaller-scale producers competing in the open market faced a particularly dire situation.

Smaller-scale producers interested in continuing operations into the foreseeable future are looking at alternative marketing structures and production technologies. To that end, some niche markets have presented opportunities which incorporate higher-price and more stable markets, as well as requiring less capital-intensive methods of production. The potential of such niche marketing has increased with the growth of natural and organic food markets over the past 20 years.

To avoid confusion about the definition and use of the terms 'natural' and 'organic' pork in the remainder of this paper, note that the US Department of Agriculture (USDA) allows for a product to be labeled as natural if the product contains no artificial ingredients, coloring ingredients or chemical preservatives, and that the product be no more than minimally processed (USDA, 1982). Many other claims related to the production protocols of pork producers

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that are often associated with the 'natural' (e.g., no antibiotics used during raising, or animal welfare claims) are, in fact, independent of the 'natural' label. Such claims must be specific, verifiable, and not misleading (e.g., 'no growth hormones' is misleading in pork production because they are already prohibited). Given the regulatory breadth for natural products, it should be noted that different processors have different requirements on what production protocols must be used for natural pork under their label. With regard to organic products, the USDA established national standards for organic products and labeling on December 20, 2000. These standards take full effect on October 21, 2002 (USDA, 2000). The guidelines for organic production are very specific and much more extensive than the 'natural' label; therefore, the best resource for detailed information is the National Organic Program of the USDA (http://www.ams.usda.gov/nop/).

To assess the viability of the natural and organic niche markets adequately, producers must not only consider the incorporation of different production technologies, but should also understand the market that they will enter. In general, farmers need more information on the nature and characteristics of the demand for natural and organic pork products, such as the price premium over conventional pork products that consumers would be willing to pay. In addition, farmers must consider how much of this premium they will realize as profit, depending on the mechanism by which they market the product. Not only must producers be concerned with the current premium, but also whether the premium will persist as more farmers begin to supply the natural and organic market.

The first objective of this research was to collect much of the recent literature on consumer interest and willingness to pay for organic products, pesticide residue-free produce, environmentally friendly products, and/or food products that are perceived as safer by consumers. In addition, anecdotal evidence from pork producers was found to indicate the level of premiums that producers might hope to obtain by entering natural or organic pork markets. Second, evidence from one study is used to argue that premiums for natural and organic pork will persist into the future. Finally, the importance of the marketing process was also investigated and various impediments to securing the hoped-for premiums are discussed, in order to give producers an idea of what they should consider in their marketing decisions.

Consumer Preferences for Pork Product Attributes

Thompson (1998) reported that while organic food is currently a small share of retail sales, its growth is quite rapid, i.e., an average of 24% annually for the past decade. Richman (1999) found that 43% of consumers look for official organic seals on processed food packages when deciding whether or not to buy them for the first time, and that 28% of consumers buy natural or organic foods at least once a week from supermarkets. According to the Food Marketing Institute, 59% of consumers look for and purchase products labeled as natural, and 37% look for and purchase products labeled as organic (FMI, 2000).

While it is clear that there is a potential market for natural and organic products, what are the attributes that consumers value about natural and organic products? A great deal of research has sought to delineate which segments of consumers are at least interested in perceived food safety attributes. Richman (1999) notes that 66% of consumers believe that pesticide and herbicide residues are serious health risks, 75% of those that normally buy organic produce consider long-term health effects to be a 'very important' factor in deciding whether to buy non-organic produce, and 37% seek out and purchase food labeled as organic due to nutrition concerns. Baker and Crosbie (1994) found that 29% of consumers value price over safety measures, 55% consider price and quality alongside certification of safety, and 16% place emphasis on pesticide regulation and safety.

Other research addressing similar consumer concerns has been able to locate target segments. McGuirk et al. (1990) divided consumers into three segments, based on the strength of their preferences with regard to food safety, nutrition and price. These are: segment 1, consisting of 38.7% of consumers who are highly concerned about food safety; segment 2, consisting of 37.3% of consumers who are highly concerned about food safety and nutrition issues as well as being price conscious; and segment 3, consisting of 23.9% of consumers who have few concerns about food safety and nutrition issues and consequently do not take time to ensure that the foods purchased were wholesome or safe to eat. In one part of the study, consumers were asked to rate various food attributes based on the following scales: 1 = serious health hazard, 2 = somewhat of a health hazard, 3 = not a hazard, or 4 = do not know. For example, in Table 1, segment 3 rates the hazard of additives and preservatives at 2.24, while segment 1 rates the hazard of additives and preservatives much higher, at 1.61, leaving a divergence of hazard assessment of 0.63. Relative to nitrates, segment 3 again rates the hazard as much lower

Table 1. Average consumer ratings of concerns about attributes related to pork.[1]

	Segment 1 (38.7%)	Segment 2 (37.3%)	Segment 3 (23.9%)
Additives and preservatives	1.61	1.90	2.24
Nitrates	1.71	1.78	2.31
Antibiotics and hormones	1.55	1.39	1.77

[1] From survey results by McGuirk et al. (1990).
Numbers refer to the degree to which a particular segment rates the hazard associated with a particular attribute, with 1 = serious health hazard, 2 = somewhat of a health hazard, 3 = not a health hazard.

than segment 1. However, the general concern about antibiotic and hormone hazards is much greater for all segments, with their hazard ratings being 1.55, 1.39 and 1.77, respectively. In addition to these risk assessments, the study indicates that segment 1 consumers are likely to pay significant premiums because of their concerns about perceived food safcty. Segment 2 appears to be more price conscious; however, they were also more likely to be responsive to advertisements of new offerings of products and willing/able to pay some premium for products with greater perceived safety.

Kinsey et al. (1993) found in the Minneapolis-St. Paul area that 11% of consumers are concerned about chemicals in meats, 52% about food safety, and only 19% primarily with prices. With regard to consumer preferences for pork, Misra et al. (1997a) studied consumer attitudes to recombinant porcine somatotropin (rPST), a synthetic hormone which is intended to increase the weight gain of hogs. They found that 60.7% of consumers are extremely concerned about the use of food additives, 57.6% about rPST, 51.1% about the use of irradiation, and 49.7% about antibiotic use.

The above information provides strong evidence that consumers are very concerned about the safety and healthiness of the food they consume. There is also evidence to suggest that consumers are concerned about how food production affects the environment. Hurley and Kliebenstein (1998) found that many consumers value environmentally conscious production of pork. Govindasamy et al. (1997) also provide some evidence of health and environmental concerns. Kinsey et al. (1993) found that the niche for environmental meats is 28% of consumers; however, in a more recent study, Richman (1999) found that 71% of consumers are somewhat or very interested in buying foods produced in an environmentally conscious manner.

Drawing from Dimitri and Richman (2000), Grannis and Thilmany (2001), Kinsey et al. (1993) and McGuirk et al. (1990), the following is a general listing of the priorities of consumers for food attributes in order of importance:

1. Food safety and healthiness:
   (a) no growth hormones;
   (b) no antibiotics;
   (c) meat not treated with chemical additives or preservatives.
2. Environmentally conscious production:
   (a) animals raised to protect air and water quality;
   (b) animals raised to protect endangered species.
3. Animal welfare:
   (a) animals not raised in small or crowded pens;
   (b) animals pasture-raised and fed grass.
4. Animals born and raised locally.
5. Animals raised in a comprehensively organic manner.

This ranking makes clear that consumers value first the final product attributes, i.e., no hormones, antibiotics or chemicals. Hog producers can control the first two of these items, but they must have relationships with processors to assure the third. The environmental attributes come second in terms of importance to consumers; while animal welfare comes third. Producers have almost complete control over these product attributes. Location ranks quite low as a consumer concern, and, interestingly, that animals are raised in a comprehensively organic manner is of least importance. Once a product incorporates the first three priorities, even if a product is not completely organic, one might consider that the difference in the mind of the consumer is likely to be negligible.

This collection of information indicates significant support for the notion that market segments exist for natural and organic production. Based on these segment and survey studies, one could say that between 40% and 80% of all consumers are the potential market for natural and organic pork products, with its perceived safety being the biggest drawing factor and others being of lesser importance. As a caveat, it should be noted that few of the studies address the confounding problems of food taste or quality with these other attributes. Buhr (1993) finds in experiments that many consumers are willing to pay more for leaner meat, even if it is produced using growth hormones. When producers consider entering the natural and organic pork market, they must pay careful attention to how these production methods affect meat taste and quality. In short, consumers want to avoid many attributes of conventionally produced pork, but they also want a tasty and otherwise healthy (e.g., lean) product.

Consumer Willingness to Pay for Natural and Organic Pork

Based on the above information, it is evident that there is a general concern about food safety and willingness by consumers to buy products with certain attributes found in natural and organic foods. How might this broad consumer sentiment translate into retail and farm premiums? Most of the evidence shows potential for premiums at the retail level. However, direct evidence from farmers and marketing firms shows that significant premiums can be obtained at the farm level as well.

Park and Lohr (1995) note that price premiums are typical for organic products, and that growers may receive up to 250% more for organic than non-organic products, with the highest premiums being paid for fruits and vegetables and the lowest for grain products. They note that consumer and retailer surveys suggest that price premiums for fresh and processed organic foods in retail supermarkets range from 5 to 450%, with an average of 30% for fresh produce. Jolly (1991) found that the average premium that consumers were willing to pay for an organic product was 37.1% above the conventional price. According to Richman (1999), 34% of consumers are willing to pay a 10% (or greater) premium for organic produce, while 46% are willing to pay a 10% premium for foods produced in an environmentally conscious manner.

Evidence of premiums directly related to pork markets

Two studies provide evidence of the level of willingness to pay for pork with specific attributes. Grannis and Thilmany (2001) used market surveys to obtain estimates of consumer willingness to pay for natural pork products such as ham and pork chops. Their study showed that likely target markets for organic and natural pork are those consumer segments concerned about feed additives and/or the effect of pork production on the environment. Table 2 shows that a significant proportion of consumers are willing to pay 9% and 10% premiums for natural ham and natural pork chops, respectively. Their study also indicates that 14% and 6.1% of consumers are willing to pay 18% premiums for natural ham and natural pork chops, respectively.

Hurley and Kliebenstein (1999) used experimental auctions to evaluate consumer willingness to pay for pork products which were produced using environmentally sustainable methods. The main environmental attributes which they considered were surface and groundwater quality and livestock odors. The main result is that the most environmentally raised 0.907 kg (2 lb) and 3.175 cm (1.25 in) thick pork loin chops could obtain a price of US$1.94 or a 22% premium over regular prices at the time of the study. These researchers defined the 'most environmentally-raised pork product' as being produced in a way that results in 80–90% odor abatement and 40–50% reduction in surface water pollution.

While no definitive premium amount was indicated in a recent study by Armah and Kennedy (2000), their results support the notion that large segments of the population are willing to pay more for pork with specific attributes such as being raised in pastures or an otherwise unconfined environment.

Evidence of premiums from non-pork markets

Westgren (1999) reports that producers participating in the Label Rouge system for marketing organic poultry in French markets receive premiums, on average, 88% above that received by conventional producers. The Label Rouge system focuses on providing chicken (*Gallus domesticus*) which have much lower levels of salmonella contamination than conventional systems (e.g., only 2% of Label Rouge birds are contaminated with salmonella compared with 69.8% of birds produced in conventional systems). It also capitalizes on consumer interests in 'green' production. These techniques include reduced spatial concentration of birds in production facilities, controlled but increased access to the outdoors, and cleaner facilities with higher waiting periods between flocks than in conventional systems.

For the specific attribute of being pesticide free, Misra et al. (1997b) found that 46% of consumers are willing to pay premiums for produce that are certified as pesticide free. Of those willing to pay price premiums, 33% are willing to pay 6–10% more, 6% are willing to pay 11–15% more, 7% are willing to pay 16–20% more, and 1% are willing to pay greater than 20% more for pesticide-free products.

Table 2. Consumer willingness to pay premiums for natural ham and pork chops.[1]

Natural ham		Natural pork chops	
% premium	% of sample	% premium	% of sample
9	39.4	10	29.6
18	14.0	18	6.1
27	4.5	26	1.8
36	1.6	36	0.6
46	0.6	46	0.2

[1]From survey results by Grannis and Thilmany (2001).

Demographics of those willing to buy and pay premiums

Grannis and Thilmany (2001) reported that consumers with high incomes, consumers who purchase pork frequently, and those who purchase natural beef are most likely to pay premiums for natural pork products. Armah and Kennedy (2000) indicated that:

1. urban dwellers were 28% more likely to pay a premium for pasture-raised pork;
2. individuals with greater than a high school education were 37% more likely to pay more for pasture-raised pork; and
3. families with incomes greater than US$50,000 were 27% more likely than those with lower incomes to pay more for pasture-raised pork.

In non-pork markets, Thompson (1998) found that consumers in the western US appear to have a greater likelihood of using organic products than in other parts of the country. Govindasamy and Italia (1999) reported that females, consumers with higher annual incomes, younger individuals and those who usually, or always, purchase organic produce are more likely to pay a premium for organic produce. Jolly (1991) found that individuals in one or more of the following categories tended to be buyers of organic produce:

1. consumers aged between 30 and 50;
2. white-collar workers;
3. service sector workers; and/or
4. small-city dwellers.

The degree to which retail premiums are transmitted to producers

The above evidence suggests that significant premiums can be obtained for natural and organic pork at the retail level. While not verifiable, one might infer that premiums between 10% and 50% are reasonable for natural and organic pork at the retail level. From discussions with two

natural and organic pork producers and one marketing firm, in the fall of 2000, it was found that one processor/marketing firm paid US$6.00 per cwt (cwt = 100 lb or 45.4 kg) over the mean market price in Iowa/southern Minnesota, with a minimum price of US$40 cwt^{-1}. At that time, the same firm would pay US$65 cwt^{-1} live weight for organic pork. Another national cooperative was found to be paying an average of about US$50 cwt^{-1} for organic pork. In its promotional material, the cooperative indicates a pricing policy based on costs of production and maintenance of a fair price that is independent of commodity pricing. One small-scale producer does direct marketing and receives US$50 cwt^{-1}. It should be noted that this same producer also handles all processing and marketing in a separately held food company. Given that market prices per cwt ranged between US$40 and US$50 in 2000, these premiums do not seem substantial. However, it is worthwhile noting that these premiums existed even when prices were lower, as in 1998 and 1999, thereby providing some stability to producers' incomes.

Sustainability of Premiums: Will the Premiums Persist?

Park and Lohr (1995) developed a model to investigate whether premiums for organic produce will persist over the long run. Given the relative generality of their model and focus of their study on the market for organic products, their findings should have relevance for pork markets. The premiums for organic produce exist for two important reasons.

1. Excess demand for organic products drives prices upward relative to conventional products.
   (a) Excess demand is driven by the perceived safety of these products.
   (b) Demand is also driven by the perception that organic products embody attributes related to improved environmental quality. That is, consumers believe that conventional production may have the unintended effect of polluting the water and air (Hurley and Kliebenstein, 1999). As such, consumers view the premiums paid to organic producers as implicit rewards to such producers for reducing the pollution associated with production. However, it should be noted that perceptions will change as consumers realize that conventional producers have, or are incorporating, odor abatement and effluent reducing technologies.
   (c) An additional source of increased demand not cited by Park and Lohr (1995) would be consumer perception that natural and organic production provides for improved animal welfare.
2. High costs of organic certification and inefficiency in transportation constrains the responsiveness of supply to the increasing demand.

In order to address the question of whether such price premiums will persist, it is argued that supply and demand factors must be identified and evaluated. Park and Lohr (1995) note that price premiums for organic produce are encountered at all levels of the marketing chain, but their persistence when challenged by supply increases is in question.

In their study, Park and Lohr (1995) accounted for differences across commodities by postulating faster rates of price and quantity adjustment if the crop is less perishable. That is, for an expected rise in prices, the change in the quantities of a crop supplied to the market will depend on whether a crop is perishable/easily storable or not. For example, if grain producers expect prices to rise in the coming marketing period, they may increase their production more rapidly than fresh vegetable producers. Grain producers can more easily store their crop to wait for higher prices than fresh vegetable producers; therefore, fresh vegetable producers are more susceptible to downside risk if prices do not increase as expected. As such, for markets where goods are very perishable, market conditions (i.e., price changes) affect quantity supplied at a slower rate than for markets with less perishable goods. Since one might consider pork to be more costly to hold after a given marketing period, the above discussion implies that increases in supply are unlikely to keep pace with the expected increases in demand which cause higher expected prices. As a consequence, price premiums are likely to persist over the medium term. Park and Lohr (1995) argue that while decreases in the marketing margin and improved management of seasonality in production and marketing will increase output, demand factors overall play a greater role in expanding organic produce markets and maintaining premiums.

Impediments and Opportunities in Marketing Natural and Organic Products

Many consumers desire increased production of natural and organic products and are willing to pay more for them, but producers must find ways to reach this potential market. Dimitri and Richman (2000) indicate that market obstacles faced by organic farmers are similar to those faced by conventional farmers, i.e., where to market products and how to receive the highest possible prices. However, there are other challenges for natural and organic producers:

1. gaining market access;
2. obtaining price and other market information;
3. maintaining the uniqueness of the product through appropriate labels;
4. infrastructure limitations;
5. potentially increased distance to markets; and
6. growing market entry by large corporations.

Gaining access to markets is often the most difficult step in selling a product. Mass market retailers frequently cannot purchase natural or organic foods from the suppliers that they regularly deal with; therefore, building relationships with new suppliers is costly. Furthermore, many retailers perceive that natural and organic foods suppliers fail to provide the level and type of service that retailers are

used to receiving (Richman, 2000). To combat these perceptions, producers must commit to developing market plans and describing the marketing potential for their products (Grannis and Thilmany, 2001). Lohr and Semali (2000) highlight the importance of a focused effort on the part of the organic industry to educate store managers on the advantages that consumers perceive about organic foods, as well as to provide clear indications as to the level of premiums. For example, producers must show that there are opportunities for mass market operations to reap benefits from entry (e.g., the US natural and organic foods market grew from US$5.49 billion in 1997 to US$8.77 billion in 1998, an increase of 59.7%) (Richman, 2000).

In terms of obtaining price and other market information, Richman (1999) reported that one-third of conventional producers view pricing and marketing as a barrier to further development of the natural and organic foods markets, while only about 14% of natural and organic foods producers regard this as a problem. Research on preferences and premiums presented above provides an indication as to what pricing retailers may expect; however, the SPINS company (www.spins.com) has scanner data on sales of natural and organic products which could further support such education initiatives. Despite the growth in information at the retail side, it has been found that producer price information is extremely difficult to find, thereby limiting the amount of information available to producers, needed for their decisions to choose to produce natural or organic pork products. In other words, companies that buy, process and sell organic products must also make their procurement process more transparent to attract potential suppliers.

Marketing of natural and organic products also relates to the problem of quality signaling. Producers must be able to differentiate their product if they are to obtain the premiums from the unique bundle of attributes they offer (Grannis and Thilmany, 2001). Unfortunately, there is a potential for problems of confusion and deception in the area of labeling (Van Ravenswaay, 1996). Forty percent of natural and organic foods producers regarded developing appropriate labels as a potential problem for the natural and organic foods market (Richman, 1999). Except for a few, clearly branded labels for natural and organic pork, evidence has been found of cases where a natural producer was deceptive in its marketing practices. One firm claims to be the only 'USDA Certified' natural grower of pork—a claim that a review of the labeling regulations will indicate as a false, or at least a strongly misleading, statement. To combat such elements in the industry, natural and organic producers would be well served if they were to cooperatively police their marketing channels and labels. In the end, the value of natural and organic pork to producers depends very much on maintaining the integrity of labels. However, even if such labeling problems are overcome, producers must consider the relevant costs associated with labeling and proof of compliance, in their choice to enter natural and organic production, i.e., labeling fees and increased record-keeping costs (Van Ravenswaay and Blend, 1997).

Further complicating the process of marketing is the lack of distributors qualified to handle natural and organic products (Van Ravenswaay and Blend, 1997). That is, to be able to maintain the identity of the natural or organic product, there is a necessity for systems that can undergird the labeling mechanism. Many researchers have begun to investigate traceability (i.e., the ability to trace a food product from one point in the food system to another point) as an integral component in the differentiation of products, but it is important to remember that the ability to trace a pork chop back to its producer is not the same thing as telling the consumer that the good is natural or organic and having the production and distribution protocols to back up such a claim. Essentially, traceability becomes a means for backing up a brand of product and increasing consumer confidence that a product labeled as 'organic' or 'natural' is, in fact, what its label says. Producers and retailers must balance the costs and benefits of increasingly traceable systems. Is it good enough to provide strict assurances that a product was produced and distributed according to organic standards, or is it necessary to allow a consumer to be able to trace the actual producer of a given pork product? (Buhr, 2002).

An additional impediment, which has not been mentioned in other research but which farmers must keep in mind when considering altering their production methods, is the question of space and distance. Assuming that premiums exist and that farmers have access to markets, the cost of shipping to a market that buys organic pork may exhaust the premium obtained in that market. Some arguments have been made that consumers who prefer natural and organic products may also prefer local production of the products. Grannis and Thilmany (2001) indicate that consumer preference for locally produced pork is quite low. Applying Hotelling (1929), one can easily show that distance and the spatial nature of markets provides a further impediment to the exploitation of natural and organic markets by small-scale pork producers. Suppose that the price on delivery of organic pork is US$55 dollars; while the price on delivery of conventional pork is US$45 dollars. Assume, for the moment, that production costs are the same for either method, and let the cost of transportation per cwt be US$0.03 km^{-1} (US$0.05 $mile^{-1}$). If a producer is 290 km (180 miles) from the delivery point for organic pork and only 32 km (20 miles) from the delivery point of conventional pork, then there would be little difference between the returns from producing organic pork and producing conventional pork. That being said, if such a producer is able to sell some natural or organic pork locally at a premium, they may find it profitable to produce natural and organic pork.

A potential problem with marketing natural and organic pork is that producers must contend with the entry of large agribusiness firms that see natural and organic markets as an

area in which to develop a high profit venture. However, Dimitri and Richman (2000) note that viability of natural and organic farmers in certain product markets has not been seriously jeopardized by the entry into these markets by large corporations such as General Mills (headquartered in Minnesota) and Dannon (headquartered in New York). The same situation could well exist in the natural and organic market for pork, such that premiums could persist even after the entry of other larger players. Also, small organic farmers in other sectors do not seem to be experiencing difficulties as severe as those of conventional farmers, who are struggling to compete with large conglomerates in conventional commodity markets. Given the discussion of the Park and Lohr (1995) study, these results are not surprising, since demand is likely to be the driving factor for premiums in natural and organic markets, especially considering the short- and medium-term conversion costs for large-scale producers relative to those for smaller-scale producers.

In terms of current marketing channels used for natural and organic products, Dimitri and Richman (2000) reported that 72% of natural and organic livestock and animal-product farmers market through wholesalers, 8% to retailers and 20% through other channels. A number of options have been sought to either eliminate these obstacles to the retail markets or to even circumvent them. Some natural and organic producers have their pork processed on contract and sell their products directly or to local restaurants and retailers. Perusal of the Internet shows that increasing numbers of farmers are also trying to harness it to reach broader markets. However, individual producers should seriously weigh the costs of setting up an independent web site against the fact that the Internet will not likely provide a large share of their sales, given the local availability of natural and organic pork in many of the markets they are trying to reach. Simply put, consumers do not need to use the Internet to find natural and organic pork. However, there may be some value to turning to larger buyers and cooperatives that process and distribute natural and organic pork, so as to leverage their skills in reaching a national market. Three marketing ventures that have grown to be national distributors of natural and organic pork products include Niman Ranch (headquartered in California), the Organic Valley Family of Farms (headquartered in Wisconsin) and Applegate Farms (headquartered in New Jersey). Niman Ranch and Applegate Farms buy pork from producers that meet their criteria and handle the processing and marketing themselves. Organic Valley is a farmer cooperative that processes and distributes the products of its members. These ventures represent marketing channels that could be useful for independent producers over the long run if they desire to produce natural or organic pork.

Conclusions

Demand will drive the development of natural and organic pork markets. Consumer concerns about food safety, environmental management and animal welfare form the foundation of various niches that will support this demand. This paper presents evidence that this demand will provide a strong base, supporting higher prices for natural and organic pork relative to conventional pork products. Thus, natural and organic production is a potentially viable opportunity for smaller niche producers to obtain greater revenues from their operations. Moreover, since the market demand for such products is growing at a rapid pace relative to the demand for conventional pork products, increases in supply from larger producers are unlikely to make a substantive cut in these premiums over the medium term, thereby allowing premiums to persist.

The works of Honeyman (1991, 1996), Hayes et al. (2000), Larson et al. (2001) discuss the costs and benefits of natural and organic pork production. The evidence they provide suggests that the major costs to small-scale producers in shifting from conventional to natural/organic production would primarily involve the development of the necessary human capital and managerial skills in changing production from capital-intensive methods to the more labor-intensive methods of natural and organic production. For producers with aging capital structures, the transition will likely be easier, but for all smaller producers it will introduce a greater flexibility and decreased overall exposure to the volatility of both hog and financial markets. For the smaller producer, natural and organic production introduces a greater degree of flexibility in their production. With lower capital requirements, natural and organic production makes it possible for smaller producers to enter and exit the markets with greater ease, thereby allowing even marginal producers to remain in the market for many years, despite potential volatility in market prices.

While the revenue and cost sides of the producer's equation appear to support the notion that entry into natural and organic markets is a viable alternative for pork producers, there are institutional and spatial barriers between the retail- and the farm-level of this market that will impede rapid development of this opportunity for producers. While there are local channels for natural and organic pork products, and a few national channels (Applegate Farms, Niman Ranch, Organic Valley) for natural and organic pork products, information regarding these channels has only become widespread recently. Furthermore, while the price premiums discussed above provide evidence that producers could improve the level and stability of their revenues by entry into natural and organic pork production, the lack of uniformity of markets, and overall thinness of these markets, present barriers for new entrants. While farmers already in these markets have gained access to marketing channels, the limited information available on them presents a short-term adjustment cost to farmers considering natural and organic pork as a niche product. In addition, the transportation costs for servicing such markets also provides a spatial barrier to entry.

On the other side of this question of impediments lies the broader retail market. Retail firms must believe that they

will have a steady and consistent supply of product if they are to provide broader support for natural and organic pork products. Given the assurance of steady premium prices is evidence that retailers will profit from selling natural and organic pork. Provided that producers, processors, wholesalers and retailers can collaborate to eliminate any concerns about steady and consistent supplies, it is likely that much of the market access problem can be overcome.

This paper concludes with a few simple recommendations to natural and organic producers as well as potential entrants. First, producers who wish enter natural and organic pork markets need to coordinate with processors to assure that their meat is processed according to the standards established by the USDA. Also, for the sake of the integrity of other non-organic labels, it is vital that natural and organic producers and processors clarify and make their claims uniform. While organic standards are now a legal fact, a few errant producers or processors could seriously affect the value perceived by consumers of products that carry other, less stringent, claims. Second, natural and organic producers must invest time and money in educating local, regional and national retailers as to the demand and expected price premium for natural and organic products. That being said, it would also be worthwhile to producers and processors of natural and organic pork to coordinate more carefully with transporters and handlers of their products, so as to further reduce the costs of handling and segregation of natural and organic products. Finally, natural and organic products have penetrated the market over several decades of 'word of mouth' marketing; it may now be worthwhile for natural and organic producers to more broadly advertise the benefits and values of their products, in order to further penetrate and strengthen the niche to which they are marketing.

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How do farmers who adopt multiple conservation practices differ from their neighbors?

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Abstract. *Wind erosion is a serious environmental problem in the inland Pacific Northwest, US. In addition to on-farm damage to soil and crop quality, it causes off-farm damage, including human respiratory illness, traffic accidents and diminished recreational values. Three key practices for effectively controlling wind erosion in eastern Washington are reduced tillage, continuous spring cropping and vegetative wind strips. Although these are effective in controlling wind erosion, their adoption by farmers in the region has been slow. Technology adoption theory has been classified into three paradigms: income, utility and innovation-adoption. This study on adoption of wind erosion control practices draws from all three paradigms. However, unlike most past research, this study distinguishes between single-practice adopters and multiple-practice adopters, and compares single-practice adopters with zero-practice adopters. Data were obtained from a random sample survey of 266 farmers in six semi-arid counties in a region of east-central Washington State prone to wind erosion. Statistical results revealed: (1) that adopters of multiple conservation practices contrast more sharply with non-adopters than do adopters of a single conservation practice; and (2) adopters of a single practice differ more from zero-practice adopters than they do from all other farmers (including adopters of other practices). More specifically, this study recognizes heterogeneity among 'adopters' in erosion control, and suggests that there may be some hierarchy among adopters in strength of innovation. It also supports earlier findings by sociologists that early adopters have more financial resources or larger farms and that education may aid adoption. Adopters were more aware of an erosion control educational program. Multiple-practice adopters are a distinct identifiable group, who may play a key role as innovators who can influence neighbors to adopt effective conservation practices. These individuals also possess unique information on the comparative cost, yields and technical challenges of alternative conservation practices that could be used on farms with similar soil and climatic conditions. Knowledge of the attributes associated with innovative multiple-practice adopters may permit soil conservation policymakers and field staff to target educational programs more accurately during the early stages of technology dissemination. Conservation-practice dissemination strategies may benefit by including innovative farmers in leadership roles in the initial stage of conservation education programs.*

Key words: adoption, conservation, logit, multiple adopters, single adopters, soil conservation, technology adoption, wind erosion

Introduction and Background

The threat of wind erosion in destroying plant and human communities usually conjures up images of the 1930s Dust Bowl in the US Great Plains. The Pacific Northwest (PNW), in contrast, evokes images of abundant precipitation and carpets of coniferous forest. While the west sides of Washington and Oregon fit this popular image, much of the east sides of these states lie in the rain shadow of the Cascade Mountains and receive only 6–20 in. (150–500 mm) of annual precipitation. The region also experiences high wind. For example, a 5–year study at Hermiston, Oregon showed that the wind speed exceeded 15 miles h^{-1} (24 km h^{-1}) 30% of the time during the period from March to June and 13% of the time during July through October (Papendick, 1998). Many of the soils in this region are relatively fine textured loess or weathered soils which are vulnerable to wind erosion.

Wind erosion has been a serious environmental problem in the inland PNW since settlers began cultivating the fine soils 120 years ago (Busacca et al., 1998). Loss of productivity inflicted by the removal of topsoil, and physical damage to crops by abrading dust and sand, has always been a major concern among agriculturalists in the dryland regions. More recently, airborne dust pollution has attracted increasing attention due to off-site effects, including damage to human health, traffic safety, industrial and household cleaning costs, and diminished recreational

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values (Veseth et al., 1994). Particulate matter (PM) 10 μm or smaller, and especially 2.5 μm or less, in aerodynamic diameter (PM–10 and PM–2.5, respectively) is readily inhaled and can accumulate in lung tissues. These particulates have been related to heart and respiratory illness (Schwartz, 1996). Federal clean air laws specify maximum levels of particulate matter in the air to ensure public health and safety. These standards are established by the US Environmental Protection Agency (EPA) regulations in accordance with a series of Federal air pollution control acts, the Clean Air Act Amendments of 1990 being the most recent. Violations of Federal air quality standards mandate that regional air quality agencies develop plans for reducing air pollution. Because agriculture is a major contributor to airborne pollutants in the PNW, it is important that research should aid adoption of conservation practices that control windborne dust to tolerable levels.

Three key practices for controlling wind erosion in eastern Washington are reduced tillage (no-till or min-till), continuous spring cropping and vegetative wind strips. No-till reduces wind erosion by seeding new crops into the stubble of the previous crop, thereby leaving a protective stubble residue of surface between crops. Continuous spring cropping leaves stubble of the previous crop intact over winter. Planting a new spring crop the following spring after a brief tillage continues protection against wind erosion. This system contrasts with the traditional winter wheat-fallow system in the region, in which the field is left in a vulnerable fallow or autumn-seeded condition three-quarters of the time. Finally, wind strips of perennial grass both reduce the magnitude of dust-cascading 'blow outs' and also capture dust particles from upwind sources. Studies have shown the effectiveness of reduced tillage and other conservation practices in controlling on-site erosion as well as off-site damage in this region. For example, continuous spring cropping was projected to reduce airborne dust by 95% compared to conventional tillage wheat–fallow (Lee, 1998). The same study showed minimum tillage wheat–fallow was projected to reduce airborne dust by 54% compared to conventional tillage wheat–fallow. The Conservation Tillage Information Center (CTIC, 1998) reported that farmers in the western states used minimum and no-tillage on 34% of the cropland. However, in east-central Washington, where wind erosion is most severe, even minimum tillage fallow is rare. For example, in Adams County, the heart of Washington's wheat (*Triticum aestivum* L.)–fallow area most vulnerable to wind erosion, conventional tillage was still practiced on 88% of the cropland in 1998 (CTIC, 1998).

Design and implementation of programs and policies to accelerate adoption of conservation practices can be assisted by empirical study of the adoption process for these practices in the study region (Wandel and Smithers, 2000). Technology adoption has been a major part of the agricultural research agenda of economists and sociologists for several decades (Byerlee and de Polanco, 1986; Diebel et al., 1993; Feder et al., 1985; Griliches, 1957; Jensen, 1982; Ruttan, 1996). A considerable number of studies have focused on the adoption of soil conservation practices, with the majority directed to conservation tillage (Dillman and Carlson, 1982; Ervin and Ervin, 1982; Hansen et al., 1987; Lee and Stewart, 1983; Napier and Camboni, 1993; Papendick and Miller, 1977).

Determinants of conservation-practices adoption

The literature on adoption is extensive and complex. For simplicity, we identify three 'paradigms' which have emerged to explain conservation-practice adoption (e.g., Feder and Umali, 1993; Nowak, 1987; Ruttan, 1996; Wandel and Smithers, 2000). The *income paradigm* assumes that farmers are profit maximizers and that the technology that increases net returns to the farm-firms will be adopted (Cary and Wilkinson, 1997). This approach is consistent with the neoclassical theory of economics. The strength of this approach lies in understanding the role played by one of the major factors that motivate or inhibit innovation: changes in income. However, one of the major criticisms of this paradigm is that it fails to recognize heterogeneity among farmers' preferences (Nowak, 1987). Thus it fails to explain why certain profitable technologies are *not* adopted (Neill and Lee, 2001).

The *utility paradigm* asserts that producers make the adoption decision based on utility maximization rather than profit maximization (Caviglia and Kahn, 2001; Rahm and Huffman, 1984). The utility approach generalizes the income paradigm by looking at a broader set of motives. It can also be seen as an attempt to synthesize the income paradigm with some insights from the diffusion paradigm described below. In the utility paradigm, a producer responds to many factors, including income, but also including non-income factors such as environmental quality, social benefit and/or altruism. For example, Smale et al. (1994) maximized net income and information over a multi-period horizon. Bultena and Hoiberg (1983) used risk orientation, perceived erosion and perceived attitudes of other farmers, as well as their perception of other farmers' adoption, to explain adoption of conservation practices. In our case, a farmer may not find it profitable to adopt a technology in his planning horizon, but may do so because it contributes to perceived air quality of the community. His marginal utility from cleaner air is higher than any loss in marginal utility from decreased profit. In economic terminology, 'utility' represents the producer's preferences for these factors.

Many rural sociologists favor a third paradigm, the *innovation–diffusion–adoption* paradigm introduced by Rogers (1962), and used extensively since (e.g., Taylor and Miller, 1978). This paradigm emphasizes the role of information, risk factors and the social position of the decision maker in the community. It portrays the innovation process as somewhat similar to the spread of an

infectious disease among farm operators with different predispositions to accept change and to innovate (Feder and Umali, 1993). Thus, some researchers have provided evidence that availability of information to producers, and the level of education and experience of prospective adopters, are better determinants of adoption of new practices than income (Caviglia and Kahn, 2001). This is consistent with diffusion theory, which states that the new information is first acquired by a few innovators and early adopters and then diffuses to the majority. Innovators exhibit a high degree of opinion leadership. Put simply, farmers adopt new practices as a result of success stories from their respected and more risk-tolerant neighbors. However, some of have argued that, by itself, the diffusion paradigm provides inadequate attention to agent motivation and to model specification (Ruttan, 1996).

The current theoretical and empirical literature recognizes that adoption behavior is complex and often requires a blend of the income, utility and diffusion paradigms (Feder and Umali, 1993). Thus, researchers often include economic variables and social–cultural variables, as well as information variables, in their studies (Nowak, 1987).

Adopters and non-adopters

Most prior empirical studies have divided farmers into two homogeneous groups—'adopters' and 'non-adopters' (Cary and Wilkinson, 1997; Cornejo et al., 1994; Harper et al., 1990; Lockeretz, 1990). This approach tends to neglect the sequential process by which a farmer adopts different practices. Also, this approach, relying on binomial adoption variables, provides little discrimination on the extent and intensity of 'adoption' (Harper, 1991; Lockeretz, 1990; Rikoon et al., 1996). Because there are frequently multiple conservation practices available to farm operators, placing all adopters of a single practice into one homogeneous category of 'adopters' will not precisely discriminate the degree of innovativeness nor the amount of soil saved by adopters versus non-adopters. A non-adopter of wind strips, for example, may be using other practices, such as no-till, that are equally or more effective in controlling wind erosion. The approach used in this study is still a compromise if erosion control is the objective. The multiple-practice versus single-practice versus zero-practice categorization proposed in this study will normally be correlated with innovativeness but it will not always be perfectly correlated with soil saved. However, our experience is that adopters of multiple practices will typically save more soil. In response to this problem, Napier et al. (2000) define an 'adoption index' as a continuous adoption variable. However, while a continuous adoption variable provides a desirable theoretical solution, it may be difficult to apply in practice due to information limitations (Feder et al., 1985; Lockeretz, 1990). Moreover, in this study we are also interested in behavior—in what determines willingness to adopt. A study using the quantity of soil saved as the dependent variable would also necessarily have to model which practices are likely to be most successful in saving soil. Although one would expect that the more innovative adopters would also obtain better results (soil saved), we obtain a more parsimonious study by just focusing on adoption behavior.

In this study we provide a tractable compromise for empirical applications. To recognize some heterogeneity in soil savings among farmers, we partition the sample into three groups: *zero-practice adopters*, that is farmers who do not adopt any of the three conservation practices; *single-practice adopters*, or farmers who adopt only one conservation practice, and *multiple-practice adopters*. This categorization is compatible with the innovation–adoption paradigm because farmers who are simultaneously using two or three conservation practices could reasonably be classified as more innovative than neighbors who are using zero or one practice. This model has practical implications for conservation education programs. Conservation agencies may desire to know how farmers who adopt multiple conservation practices differ from their neighbors who adopt only one or zero conservation practices. Multiple-practice adopters can provide information to conservation agencies and to other farmers on the relative effectiveness and profitability of competing practices within the same farm. These farmers can also serve as potential leaders in conservation-practice education and diffusion programs.

Objectives

To help determine if farmers using different numbers of conservation practices are distinct identifiable groups, we tested the following two hypotheses for a random sample of 266 east-central Washington dryland farmers

Farm and farmer characteristics will differ more between adopters and non-adopters of conservation practices, when adopters are defined as those who adopt multiple practices as opposed to those who adopt a single conservation practice.

Farm and farmer characteristics will account for a greater difference between adopters and non-adopters of a particular conservation practice when non-adopters are defined as adopters of zero conservation practices (zero-practice adopters) as opposed to when they are defined as 'all other farmers'. 'All other farmers' ('rest') includes both the zero-practice adopters and farmers who have not adopted the particular practice but who may have adopted some other practice.

Methods

First we compared statistically the similarity of farm and farmer characteristics between single-practice adopters and multiple-practice adopters. The farms were divided into two groups: one for the single (multiple later) practice adopters, and the other for the zero-practice adopters. The levels of farm characteristic variables for each group were

assessed separately. *T*-tests were used to test the differences in means for all continuous characteristic variables, and the chi-square test was used to test the difference in frequency of occurrence for all categorical characteristic variables. The null hypothesis for each case was that there is no difference in a characteristic variable between single (multiple later) practice adopters and zero-practice adopter.

Our second objective was to compare the ability of farm and farmer characteristics to predict differences between adopters and non-adopters of any practice, when non-adopters are defined as farmers who do not adopt the specific practice versus farmers who do not adopt any practice. Logistic regression, an appropriate analytical tool to deal with a dichotomous criterion variable (Gujarati, 1992), was used for this comparison. The level of significance of coefficients for the same characteristics was compared across the two regression equations representing different non-adopter definitions. The dependent variable was described by a binary (zero-one) variable. Six types of adoption variables were defined (Table 1). SINGLE and MULTIPLE represent single- and multiple-practice adoption. NOTILL and CONTSP represent no-till and continuous spring cropping adoption. When these conservation-practice variables are followed by '_ZERO', adopters are contrasted with zero-practice adopters only, and when followed by '_REST', adopters are contrasted with the rest of the farmer sample. Recall that rest of the (sample) farmers includes both the zero adopters and farmers who have not adopted the particular practice but who have adopted some other conservation practice.

The seven independent variables included in this study (Table 1) were drawn from all the three adoption paradigms. The signs of their expected correlation with adoption of the three examined wind erosion control practices were based on the adoption theories discussed above. KNOWPM10 represents knowledge of a PM-10 educational program, which had been conducted in the region prior to the survey (Scott et al., 1997). This program communicated on-site and off-site damage from wind erosion and described potentially effective control practices. Consistent with the innovation and diffusion paradigm, the program is expected to have a positive correlation with the adoption of practices. EROSPROB represents an index of the number of the farmer's perceived on-site problems with wind erosion. Consistent with an environmental quality component of utility, it is expected to have a positive correlation with the adoption of practices. SIZE and %RENTED represent the number of acres farmed by the respondent and the percentage of farmland rented from farmers other than family members, respectively. SIZE may increase the financial capability of the farmer to implement conservation practices. Therefore, it is expected to contribute positively to the adoption of practices as larger farmers have the resources to be more risk-tolerant following the diffusion paradigm. %RENTED might vary negatively with adoption because a renter may not consider long-term land degradation as much as an owner. AGE,

Table 1. Variables in wind erosion control practices adoption models.

Variable[1]	Unit[2]	Description	Paradigm
Dependent:			
NOTILL_REST	(1,0)	1 if no-till or min-till, 0 otherwise	
NOTILL_ZERO	(1,0)	1 if no-till or min-till, 0 for zero practices	
CONTSP_REST	(1,0)	1 if continuous spring crop, 0 otherwise	
CONTSP_ZERO	(1,0)	1 if continuous spring crop, 0 for zero practices	
SINGLE	(1,0)	1 if single practice, 0 for zero practices	
MULTIPLE	(1,0)	1 if multiple practices, 0 for zero practices	
Independent:			
KNOWPM10	(0,1,2,3)	0 if not heard of PM-10; 1 if slightly knowledgeable; 2 if somewhat knowledgeable; and 3 if very knowledgeable	Diffusion
EROSPROB	(0,1,2,3)	0 if no problems with erosion in past 10 years; 1 if 1–2 problems; 2 if 3–5 problems, and 3 if more than five problems	Utility
SIZE	Acres[3]	Acres	Income
%RENTED	Percent	Percentage of farm land rented from other than family	Income
OFF-FARM	(1,2,3)	1 if source of household income is mostly from farm; 2 if roughly same from farm or off-farm; and 3 if mostly off-farm	Income
EDUC	(0,1,2)	0 if highest level of education is within secondary; 1 if some college or technical school; and 2 if college graduate	Diffusion
AGE	Years	Years	Income

[1] Suffixes REST and ZERO in the variable name denote that adopters are contrasted with rest of the farmer sample and zero-practice adopters, respectively.
[2] Value for categorical variables.
[3] 1 acre = 0.405 ha.

EDUC and OFF-FARM represent age, level of education and magnitude of off-farm income of the farmer, respectively. AGE is expected to have negative correlation because of a shorter expected economic payoff period from conservation practices for older farmers. Consistent with the diffusion paradigm, EDUC is expected to correlate positively with adoption of practices because it may help farmers better acquire new information and apply conservation technology. OFF-FARM could not be signed because it could either provide capital for conservation practices or dilute income incentives for conserving resources. KNOWPM10, EROSPROB, OFF-FARM and EDUC are measured as categorical variables. SIZE, %RENTED and AGE are continuous variables (Table 1).

Data

Data were obtained through a telephone survey conducted in 1997 and included a random sample of dryland farmers from Adams, Benton, Douglas, Franklin and Grant counties in east-central Washington state. The sample frame for the survey was obtained from the Farm Service Administration (FSA) (Scott et al., 1997).

A total of 266 survey responses were included in the current study. The survey obtained a relatively high final response rate for a telephone survey. The overall response ratio (completes divided by [completes + partial completes + refusals + did not reach]) for the survey was 65%. The overall cooperation ratio (completes divided by [completes + refusals]) was 78%. In order to increase cooperation, the survey followed the standard survey methods outlined in Dillman (1978). All members of the sample were sent an advance letter notifying them about the study. In addition, we speculate that the high rate of cooperation was partly due to the farmers' keen interest in wind erosion. Another possible factor may have been the trust relationship the response group had with the Natural Resources Conservation Service (NRCS) and the local Conservation Districts that sponsored and conducted the survey.

The survey took about 15 minutes for most of the respondents to complete. Most of the 60 questions were yes–no or limited categories response questions which had been tested in a pilot survey of 39 farmers (Scott et al., 1997). In general, categorical variables with a brief scale are easier to use over the telephone and often better at eliciting memories than are quantitative questions or more elaborate scales. For instance, respondents were asked which of four categories described their knowledge of PM-10, ranging from 'not heard of' (coded as 0) to very knowledgeable (coded as 3). Similarly, respondents were asked whether they had experienced four categories of problems with wind erosion over the past 10 years—with no problems coded as 0, 1–2 problems coded as 1, 3–5 coded as 2, and more than five problems coded as 3. The survey included questions on the operators' use of conservation management practices, the level of producer knowledge of PM-10 and their sources of information about dust and conservation, and basic demographic and farm operations information.

Table 2. Descriptive statistics for all variables.

			Statistics					
Variable[1]	**Value/Unit**	***N***	**% of level 0**	**% of level 1**	**% of level 2**	**% of level 3**	**Max.**	**Min.**
Categorical:								
NOTILL_REST	(1,0)	266	80	20	–	–	1	0
NOTILL_ZERO	(1,0)	215	75	25	–	–	1	0
CONTSP_REST	(1,0)	266	74	26	–	–	1	0
CONTSP_ZERO	(1,0)	230	70	30	–	–	1	0
SINGLE	(1,0)	229	70	30	–	–	1	0
MULTIPLE	(1,0)	198	81	19	–	–	1	0
KNOWPM10	(0,1,2,3)	266	27	24	40	9	3	0
EROSPROB	(0,1,2,3)	266	25	44	23	8	3	0
OFF-FARM	(1,2,3)	266	–	81	14	5	3	1
EDUC	(0,1,2)	266	27	42	31	–	2	0
			Mean		SD[2]			
Continuous:								
SIZE	Acres[3]	266	3263		2593		18,000	60
%RENTED	Percent	266	23.76		30.53		100	0
AGE	Years	266	53		13		86	26

[1] Suffixes REST and ZERO in the variable name denote that adopters are contrasted with rest of the farmer sample and zero-practice adopters, respectively.
[2] Standard deviation.
[3] 1 acre = 0.405 ha.

Adoption questions referred to wind erosion control practices used by respondents. The three conservation practices are: no-till or min-till (NOTILL), continuous spring cropping (CONTSP) and wind strips (WINDST). Adoption data were based on an initial categorical question: 'Are you currently using any of the following conservation practices?' This question and follow-up questions were appropriate to a telephone-based snapshot of current conservation practices, information and farmer types. Moreover, using a categorical variable for adoption allowed us to focus on the *behavioral heterogeneity* among types of adopters and non-adopters. We focused on the agents of change rather than the nature of the techniques.

When questioned about their current knowledge of the PM-10 conservation educational program, responses revealed that 40% were 'somewhat knowledgeable', 25% were 'slightly knowledgeable', and another 25% had not heard of it at all (Table 2). The four-category scale goes from 0 = 'have not heard' to 3 = 'very knowledgeable' (Table 1). The largest category, 44% respondent farmers, had experienced one to two 'wind-erosion problems' within the past 10 years (chosen from four categories: none; 1–2; 3–5; more than five problems in past 10 years). Wind erosion 'problems' were self-defined. On average, the farmer had some college or technical school education, which is also the largest category, 42%, for this variable. For the majority of farmers, their major source of income came from on-farm activities. Farm size varied from 60 to 18,000 acres (24 to 7290 ha) with a mean of 3263 acres (1322 ha). The percentage of land rented from outside the extended family averaged about 24%—with somewhat less than 50% owned personally by the operator. Farmers ranged from 26 to 86 years old, with an average age of 53 years. The sample displayed substantial variation in characteristics, as shown by relatively high standard deviations or large percentages in all categories (Table 2).

Results and Discussion

Figure 1 provides the percentage of farmers in each category: zero-practice adopters, adopters of any one practice, and adopters of any combinations of practices. It shows that 60.5% of the 266 farmers used none of these conservation practices, and they are defined as zero-practice adopters in this study. Only the remaining 39.5% were adopters of conservation practices. The single-practice adopters included 12.8% of the 266 farms for CONTSP, 8.3% for NOTILL, and 4.5% for WINDST, which add up to 25.6%. Dual-practice adopters, shown by the overlapping areas in Figure 1, represented 9.8% of the 266 farms using NOTILL and CONTSP, 1.9% using CONTSP and WINDST, and 0.8% using WINDST and NOTILL, adding up to 12.5%. An additional 1.5% farms adopted all three practices. These results show that 26% of the sample farms adopted CONTSP, followed by 20.3% for NOTILL and 8.7% for WINDST.

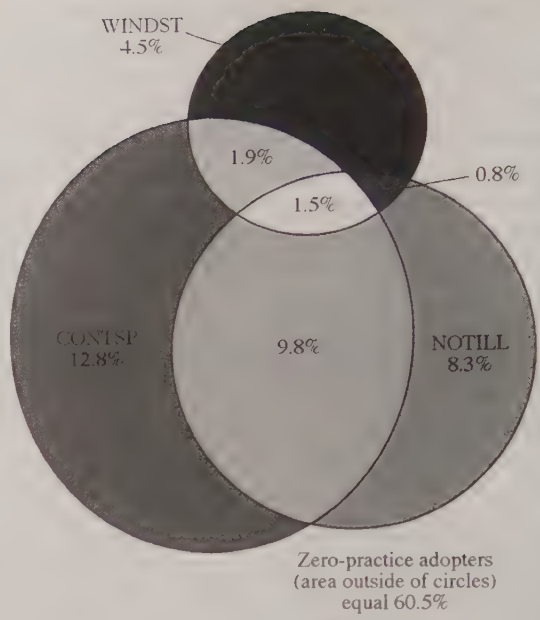

Figure 1. Percent of 266 total respondents by adoption category.

Table 2 reports basic statistics for the responding farmers. These include the number of observations, range, mean and standard deviation for continuous variables, and percentage of each category for categorical variables utilized in this study. For example, consistent with Figure 1, out of 266 farmers about one-fifth adopted no-till. The remaining farmers either adopted no conservation practice or other practices.

Table 3 evaluates the statistical difference of farm and farmer characteristics between adopters and non-adopters, when adopters are defined as single-practice adopters and multiple-practice adopters. For continuous characteristic variables, the null hypothesis is that the means of the variables are the same for adopters and non-adopters. *T* statistics are used under the assumption of an equal variance. For categorical variables, chi-square statistics are used for the test of homogeneity, and the null hypothesis is that the percentages in each category are the same for adopters and non-adopters. More specifically, Table 3 lists the probabilities of making a type I error, that is rejecting that the means are equal for adopters and non-adopters when they are actually equal. Almost all probabilities are smaller for the multiple-practice adopters versus zero-practice adopters than for the single-practice adopters versus zero-practice adopters. The only exception is EROSPROB. This shows heterogeneity among adopters, except that the variable measuring the perception of erosion on the farm does not go along the cluster of attributes that discriminate among heterogeneous adopter categories.

At the 10% critical level, the *T*- and chi-square tests show no statistically significant differences between the characteristics of single-practice adopters and zero-practice

Table 3. Comparison of single- and multiple-practice adopters to zero-practice adopters on the basis of probability of type I error[1].

		Zero- compared to single-practice adopters ($N = 229$)		Zero- compared to multiple-practices adopters ($N = 198$)	
Variables	**Tests**	**Pr. Error**	**Direction[2]**	**Pr. Error**	**Direction[2]**
SIZE	*T*-test	0.13	+	0.04	+
%RENTED	*T*-test	0.92	+	0.56	+
AGE	*T*-test	0.74	–	0.54	
KNOWPM10	chi-sq. test	0.48	+	0.21	+
EROSPROB	chi-sq. test	0.26	+	0.44	+
OFF-FARM	chi-sq. test	0.98	–	0.91	+
EDUC	chi-sq. test	0.45	+	0.10	+

[1] The null hypothesis is there is no difference between adopters and zero-practice adopters.
[2] Direction in which adopters differ from zero-practice adopters. For continuous variables it is the comparison of means. For categorical variables it is the comparison of percentages. All the categories of a variable are equally weighted for the comparison.

Table 4. No-till and continuous spring cropping adoption regression coefficients when non-adopter is defined as all other farmers versus zero-practice adopters.

Variables	**NOTILL_REST**	**NOTILL_ZERO**	**CONTSP_REST**	**CONTSP_ZERO**
KNOWPM10	0.322	0.316	0.226	0.232
	(0.058)[1]	(0.069)	(0.136)	(0.137)
EROSPROB	–0.135	–0.177	–0.135	–0.133
	(0.468)	(0.345)	(0.424)	(0.431)
SIZE	0.000162	0.000181	0.000086	0.000121
	(0.006)	(0.005)	(0.124)	(0.047)
%RENTED	–0.00112	–0.0016	–0.00225	–0.0029
	(0.839)	(0.780)	(0.653)	(0.579)
OFF-FARM	0.115	0.190	0.249	0.218
	(0.712)	(0.566)	(0.353)	(0.428)
EDUC	0.259	0.308	0.219	0.234
	(0.261)	(0.198)	(0.288)	(0.289)
AGE	0.00787	0.006	–0.0121	–0.00909
	(0.584)	(0.689)	(0.348)	(0.494)
CONSTANT	–3.062	–2.820	–1.363	–1.396
	(0.005)	(0.013)	(0.148)	(0.152)
Equation signif. (chi-sq)	(0.041)	(0.029)	(0.237)	(0.169)

[1] Significance level in parentheses.

adopters (Table 3). Only SIZE approaches significance, with a 0.13 probability level. In contrast, both SIZE and EDUC differ statistically at the 0.04 and 0.10 level between multiple-practice and zero-practice adopters. All variables conform to expected signs. Adoption theorists have argued that innovators or early adopters are likely to have more financial resources, exercise more opinion leadership and use broader sources of information (Rogers, 1962). The significance of SIZE at the 0.04 probability level might indicate greater financial resources among multiple adopters in this semi-arid region where farm size varied greatly. Higher levels of EDUC might also facilitate information acquisition and use.

Table 4 presents results of four Logit regression models with estimated coefficients, their level of significance and overall equation significance. Non-adopters are defined alternatively as zero-practice adopters and 'all other farmers'. In all four models, KNOWPM10, SIZE, OFF-FARM and EDUC are positively related to adoption, consistent with the theory discussed in the methods section. These results are also consistent with existing literature. Farm size was found to contribute positively and significantly to adoption (Feder et al., 1985; Lee and Stewart, 1983; Norris and Batie, 1987; Rahm and Huffman, 1984). Off-farm income also was found to be positively related to conservation tillage adoption (Norris and Batie, 1987; Nowak, 1987). Nowak (1987) favored the argument that farmers with more off-farm income have more flexibility to invest in practices than those with only farm income. In our case, the insignificant coefficient for off-

farm income may be due to lack of off-farm employment opportunities in the study area. Education was also found to be significant and positive by Traore et al. (1998) and Gould et al. (1989).

%RENTED is negatively related to adoption but insignificantly, which is also consistent with theory. Renters have a shorter time horizon to benefit from the soil productivity payoffs from soil conservation. Traore et al. (1998) also reported the insignificant impact of land ownership to adoption.

EROSPROB is also negatively related to adoption but is insignificant. This shows that perception of the number of erosion problems was a weak determinant of adoption. Previous studies had mixed results, which concur with this conclusion. Perception of an erosion problem was found to be positively related to adoption sometimes (Norris and Batie, 1987), and negatively related at other times (Wandel and Smithers, 2000). Cary and Wilkinson 1997 found that environmental attitudes will not translate into pro-environmental behavior unless there are economical or other benefits associated with the behavior. In our case, the explanation for insignificant but negative perception of an erosion problem may be due to the respondent's recollection of erosion problems on the farm over the past 10 years.

The two models defining non-adopters as zero-practice adopters display superior overall equation significance levels (Table 4). Furthermore, for all variables except for KNOWPM10 and AGE, the probability of type I error is higher in NOTILL_REST than in NOTILL_ZERO. The results differ for the CONTSP model. The level of significance is higher in CONTSP_REST than in CONTSP_ZERO for SIZE and %RENTED. Coefficient significance levels are very similar for KNOWPM10, EROSPROB and EDUC. However, significance of the overall equation clearly favors CONTSP_ZERO. The overall equation significance suggests NOTILL_ ZERO and CONTSP_ZERO are superior models, supporting our second hypothesis.

The level of significance of %RENTED, OFF-FARM, AGE and EROSPROB range from 34% to 84%, suggesting these variables have weak discriminating influence, in a multiple regression context, between adopters and non-adopters. KNOWPM10 and SIZE show the most consistent statistical significance at 0.05, 0.10, 0.15 levels (Table 4). Size of farm is beyond the control of conservation advocates, but it can be used as a targeting criterion for new conservation technologies.

Conclusions

Prior studies revealed a lack of rigorous distinction in the way 'adopters' and 'non-adopters' were defined. They fail to account for heterogeneity among conservation-practice adopters. Adopters have been defined as adopters of a single conservation practice without clarifying whether the 'non-adopters' used other practices or not. However, it may often be the case, as in this study, that adopters are choosing from a menu of practices. In effect, definition of non-adopters as simply all farmers who do not adopt the particular practice of interest fails to recognize the potential partial substitutability among practices, and it fails to recognize that the 'rest of farmers' category may well include adopters, albeit adopters of these substitute or alternative practices.

This study revealed: (1) that adopters of multiple conservation practices contrast more sharply with zero-practice adopters than do adopters of a single conservation practice; and (2) that adopters of a practice differ more from zero-practice adopters than they do from all other (the 'rest' of the) farmers. More specifically, it recognizes heterogeneity among 'adopters' in conserving the soil. Multiple-practice adopters are a distinct identifiable group, who may play a key role as innovators who can influence neighbors to adopt effective soil conservation practices. These individuals will also possess unique information on the comparative cost, yields and technical challenges of alternative conservation practices. Studies that identify 'adopters' as adopters of arbitrary, single soil-conservation practices may miss identifying the true innovators in terms of maximum soil savings. The approach used in this study identifies innovativeness and adoption with soil conservation performance to a greater extent. It also provides a more rigorous definition of 'non-adopters' by defining this group as zero-practice adopters. These distinctions were statistically significant in terms of farm size, education and knowledge of a conservation education program.

Results from this paper support the previous findings by sociologists that early adopters have more financial resources or larger farms (Feder et al., 1985; Lee and Stewart, 1983; Norris and Batie, 1987; Rahm and Huffman, 1984) and that education aids adoption (Caviglia and Kahn, 2001; Gould et al., 1989; Traore et al., 1998). In this study adopters were more aware of a broad wind erosion control educational program.

Knowledge of the attributes associated with innovative multiple-practice adopters may permit soil conservation policymakers and field staff to target educational programs more accurately during the early stages of technology dissemination. Conservation-practice dissemination strategies may benefit by including innovative farmers, having higher resources and education, in the initial stage of adoption.

This study incorporated all three paradigms of adoption theories: the income paradigm, the utility paradigm and the innovation-diffusion paradigm, by including farm attribute variables related to profitability, environmental quality and information. Comparatively speaking, variables drawn from the innovation-adoption paradigm appear to outweigh those from the utility paradigm, although there is overlap in linking variables to paradigms. Variables drawn from the income paradigm show mixed significance. This observation reinforces earlier research findings that adoption of soil conservation practice is driven by multiple motivations. In

part, this result is also driven by the partially overlapping explanatory factors of the three paradigms.

The approach used in this study is a partial model when reduction of erosion is seen to be the ultimate objective. The multiple-practice versus single-practice versus zero-practice categorization proposed in this study will normally be correlated with innovativeness, but will not always be perfectly correlated with soil saved, because soil saved depends on a number of additional factors, including the particular agro-climatic conditions and soil/slope characteristics at the sites of interest, and the effectiveness of the practices studied for conditions at the study sites. However, our experience is that adopters of multiple practices will typically save more soil. While the data in this study, and most surveys, will not permit direct measurement of the soil erosion on a farm, collecting actual or projected soil erosion data would be desirable when affordable. Such data would permit testing the hypothesis of a positive correlation between the number of conservation practices adopted and quantity of soil saved. A more complete data set could also permit examining the effects of more explanatory behavioral variables, such as perceived risk factors, stewardship ethics, community–social factors and the effects of agro-climatic and soil factors that might influence success. Of course, the findings from this study could also be influenced by the particular agro-climatic characteristics of the study region. Similar research using these definitions of adoption and non-adoption is encouraged elsewhere.

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Use of a mechanical roller-crimper as an alternative kill method for cover crops

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Abstract. *Cover crops have long been recognized as a beneficial component of many cropping systems; however, their use is still not commonplace. Usage may be increased by identifying more cost-effective and environment-friendly techniques for cover-crop management. This study was conducted to determine the effectiveness of using a mechanical roller-crimper as an alternative method for killing cover crops. The study location was in east-central Alabama, using a split-split plot experimental design with four replications and 3 site-years during 1999–2000. Rye, wheat and black oat were evaluated in terms of ease of kill and optimum time of kill using a roller-crimper, two herbicides (paraquat and glyphosate) at their labeled rate, and two reduced chemical (half label rate) combinations of the same chemicals with the roller-crimper. Four Feekes' scale growth stages were used to determine optimum time of kill: 8.0 (flag leaf), 10.51 (anthesis), 10.54 (early milk) and 11.2 (soft dough). Plant growth stage was the main determining factor for effectiveness of the roller-crimper for killing the cover crops. At the flag leaf stage, the roller-crimper provided only 19% kill across all covers over the 3 site-years. After plants reached anthesis, the roller-crimper with half-rate herbicide combinations equaled the effectiveness of herbicides alone at their label rate, averaging 94% kill. By the soft dough growth stage, all kill methods were equally effective due to accelerating plant senescence (95% mean kill across kill methods). Use of the roller-crimper alone after anthesis can decrease costs by as much as $26.28 per ha, while providing a kill rate equivalent to that of herbicide treatment alone.*

Key words: *Avena strigosa* Schreb., C:N ratio, conservation tillage, growth stage, glyphosate, paraquat, *Secale cereale* L., *Triticum aestivum* L.

Introduction

Cover-crop use has increased among growers in the US due to increased awareness of their benefits and greater focus on conservation (Sustainable Agriculture Network, 1998). Cover crops reduce nitrate leaching, reduce soil erosion, improve soil fertility, increase soil water infiltration and storage, and suppress weeds (Blevins et al., 1971; Dinnes et al., 2002; Doran and Smith, 1991; Kaspar et al., 2001; Munawar et al., 1990; Nagabhushana et al., 2001; Reeves, 1994). Small-grain cereals are often used as cover crops; they are adapted to many geographic areas and cropping systems and can be economically less risky than legume cover crops (Sustainable Agriculture Network, 1998; Wilkins and Bellinder, 1996). Cereals have high carbon to nitrogen ratios (C:N ratio) and high cellulose and lignin contents, which is beneficial in that residues decompose more slowly than legume residues (Morse, 1998; Munawar et al., 1990; Ranells and Wagger, 1996; Wagger, 1989). Wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) are commonly used cover crops in many areas of the US (Wilkins and Bellinder, 1996). Black oat (*Avena strigosa* Schreb.) is a cover crop widely used in Brazil (Derpsch et al., 1991) and has been introduced recently for use in the south-eastern US (Bauer and Reeves, 1999; Patterson et al., 1996; Reeves et al., 1997). Patterson et al. (1996) found that black oat matures faster than wheat and rye in warm climates and also produces a significant amount of plant biomass. Black oat has also been shown to have allelopathic properties, with the potential to control both annual grasses and some small-seeded broadleaf weeds (Bauer and Reeves, 1999; Derpsch, 1990; Patterson et al., 1996; Reeves et al., 1997). However, it has been identified as having low tolerance to temperatures less than –7°C (depending on growth stage), which may be a disadvantage by limiting the range of adaptation (Bauer and Reeves, 1999; Reeves et al., 1997).

Traditionally, cover crops have been terminated using non-selective, post-emergence contact or systemic herbicides, usually paraquat (1,1′-dimethyl–4,4′-bipyridinium) or glyphosate [*N*-(phosphonomethyl) glycine] (Anderson, 1996; Munawar et al., 1990; Weston, 1990). Both of these chemicals are effective on small-grain cereal cover-crop species (Munawar et al., 1990; Weston, 1990). Chemical

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desiccation of cover crops is highly effective and can be relatively quick, depending on the herbicide, so it is an attractive option for farmers.

However, herbicide cost is a disadvantage of this termination method and can comprise a large portion of a farmer's annual expenses (Kelly et al., 1996; Wilkins and Bellinder, 1996). In addition, there is increased concern over the use of all agricultural chemicals. Specifically, the possibility of surface and groundwater contamination (Kookana and Aylmore, 1994; Ritter, 1990), soil contamination (Kookana et al., 1995) and the potential for increased incidence of weed resistance to herbicides (Holt et al., 1993; Powles et al., 1997) have caused concern among the general public and agricultural communities. These concerns, along with increasing input costs, provide incentive for researching alternative methods to terminate cover crops.

Mechanical kill methods may serve as an alternative to herbicides. These methods might also be used in combination with herbicides to reduce the chemical rate required for kill. Mowing, rolling/slicing with coulters, and undercutting are mechanical kill methods that have been used and evaluated on a limited basis in the US (Creamer et al., 1995; Dabney et al., 1991; Hoffman et al., 1993; Morse, 1998; Wilkins and Bellinder, 1996). Dabney et al. (1991) used vertical coulters spaced 10 or 20 cm apart to chop several legume cover crops, followed by atrazine application 14 days later. Kill ratings ranged from 16 to 99%, dependent on legume species, coulter spacing and growth stage of the legumes. Hoffman et al. (1993) reported that chopping with a roller was no more effective than a no-till planter in killing hairy vetch (*Vicia villosa* Roth). Undercutters are not practical for no-tillage systems and mowers require energy-intensive power take-off (PTO)-driven equipment. Rolling drums fitted with blades (referred to as *rolo-faca* in Portuguese) have been used for many years in southern Brazil and Paraguay to terminate cover crops and facilitate planting in conservation tillage systems (Derpsch et al., 1991). Typically, the blades are dull and are designed to crush or crimp cover-crop stems, rather than cut or chop them. Energy requirements for a roller-crimper can be estimated from that required by a land roller or cultipacker (0.7–2.4 $kW \cdot h\,ha^{-1}$). This is tenfold less than the energy requirement of a rotary mower (9.2–24 $kW \cdot h\,ha^{-1}$) (Hunt, 1977). Roller-crimpers can be especially useful in conservation tillage systems, as the roller-crimper provides a unidirectional residue mat, facilitating planting operations and improving seed–soil contact and plant emergence. The use of the roller-crimper as a kill method is new to US growers, therefore more research is necessary before it will be widely accepted.

Timing of kill is also a very important component in cover-crop management, especially with the use of mechanical kill methods (Creamer et al., 1995; Munawar et al., 1990). Some researchers have noted that growth stage of a cover crop affects the ease of mechanical kill (Creamer et al., 1995; Morse, 1998). Creamer et al. (1995) showed killing cover crops of rye, hairy vetch (*Vicia villosa* L.), crimson clover (*Trifolium incarnatum* L.) and barley (*Hordeum vulgare* L.) with an undercutter to be easiest and most effective (95% kill or higher) when the cover crops were at mid- to late-bloom or later. However, many farmers determine kill time based on planting date of the cash crop, e.g., 2–4 weeks prior to cash-crop planting date, rather than at a certain growth stage. Further investigation is required to establish growth-stage-based cover-crop termination as common practice.

The objectives of this study were threefold: (1) determine the effectiveness of using a roller-crimper compared to, or in addition to, herbicides as a cover-crop kill method; (2) determine the optimum kill time for black oat, rye and wheat cover crops, using easily identified stages of the Feekes' scale (Large, 1954); and (3) identify any differences in ease of kill for these three cover crops using the roller-crimper.

Methods and Materials

The study was conducted at two locations in east-central Alabama during 1999 and one location in 2000, providing 3 site-years of data. For this location, the average frost-free growing season is 220 days and annual rainfall is 1425 mm, normally distributed throughout the year. The average annual temperature is 17.2°C, with mild winter temperatures (December–February mean temperature is 7.9°C; mean minimum temperature is 1.6°C, with an average of 29 days occurrence of temperatures <0°C during this period). The soil types (sites) in 1999 were a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) and a Cahaba sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Hapludults). In 2000, the experiment was conducted on the Compass sandy loam site. A split-split plot experimental design with four replications was used at each site-year. Whole plots were three small-grain cover crops: 'Elbon' rye, 'Coker 9803' wheat, and 'SoilSaver' black oat. Cover crops were planted at a rate of 100 $kg\,ha^{-1}$ on 18 November 1998 and 9 November 1999, using a grain drill with double-disk openers. Sixty-three kg $N\,ha^{-1}$ was applied as ammonium nitrate each season. Plots were 2.4 m wide and 7.6 m long. During the first year of data collection (1999), three easily identifiable growth stages using the Feekes' scale were subplots: Feekes' Scale 8 (flag leaf), 10.51 (anthesis) and 11.2 (soft dough). In 2000, the early milk growth stage (Feekes' Scale 10.54) was evaluated as the last growth stage, replacing the soft dough growth stage. Sub-subplots were five kill methods: roller-crimper only, glyphosate at 1.68 kg $ai\,ha^{-1}$ (label rate), paraquat at 0.69 kg $ai\,ha^{-1}$ (label rate), roller-crimper + glyphosate at 0.84 kg $ai\,ha^{-1}$ (half label rate), and roller-crimper + paraquat at 0.35 kg $ai\,ha^{-1}$ (half label rate). Since efficacy of label rates was validated by extensive data prior to registration of herbicides, we did

not include half label rate glyphosate and paraquat treatments without use of the roller-crimper.

The roller-crimper used was a drum roller with horizontal welded blunt steel metal strips, which crushed and crimped cover crop stems without cutting them. The roller-crimper drum was 2.4 m wide with a diameter of 406 mm, with seven blunt steel blades (76 mm height) placed 76 mm apart around the drum separated by inverted angle-irons with 54 mm height (Fig. 1).

All cover crops were monitored regularly to determine growth stage. Kill treatment was applied when at least 65% of the plot was at the desired growth stage. At each stage, prior to kill treatment, two 0.25 m^2 biomass samples within each subplot were obtained to determine biomass production and C:N ratio. Biomass samples were oven-dried at 65°C to a constant weight.

Percent kill measurements were taken at 7, 14, 21 and 28 days after treatment, using both a visual rating method and plant moisture content samples. Visual measurements were made using a 0–10 scale, with 0 being no kill and 10 being complete kill. Data were expressed as percentage kill by multiplying the rating by 10. Data from 28 days are presented as they best correlated with plant moisture results; although it should be noted that there was no significant difference in visually rated percentage kill at 14 versus 28 days after treatment. In conservation tillage systems, terminating covers 4 weeks prior to planting the cash crop is a standard recommendation in order to minimize potential stand problems as a result of soil water depletion, allelopathy and disease.

Gravimetric soil water content measurements were taken 28 days after treatment to determine the amount of soil water available to a cash crop. Soil water is an important consideration in cover-crop management, since creation of a water deficit by a cover crop can be a problem for the cash crop, especially in a year with low spring rainfall (Munawar et al., 1990; Reeves, 1994; Williams et al., 2000). Soil samples were taken in the top 7.6 cm of soil (cash-crop seed zone) in each sub-subplot. Samples were weighed, oven dried at 105°C, then weighed again and water content measured by difference (Gardner, 1986). Weed biomass measurements (two 0.25 m^2 per sub-subplot) were also taken 28 days after treatment to evaluate kill methods and cover crops in terms of weed control.

All data were analyzed for main effects and interactions using analysis of variance (ANOVA) (SAS Institute, 1988). Fischer's protected least significant difference (LSD) was used for mean separations. For all data, an *a priori* $P \leq 0.10$

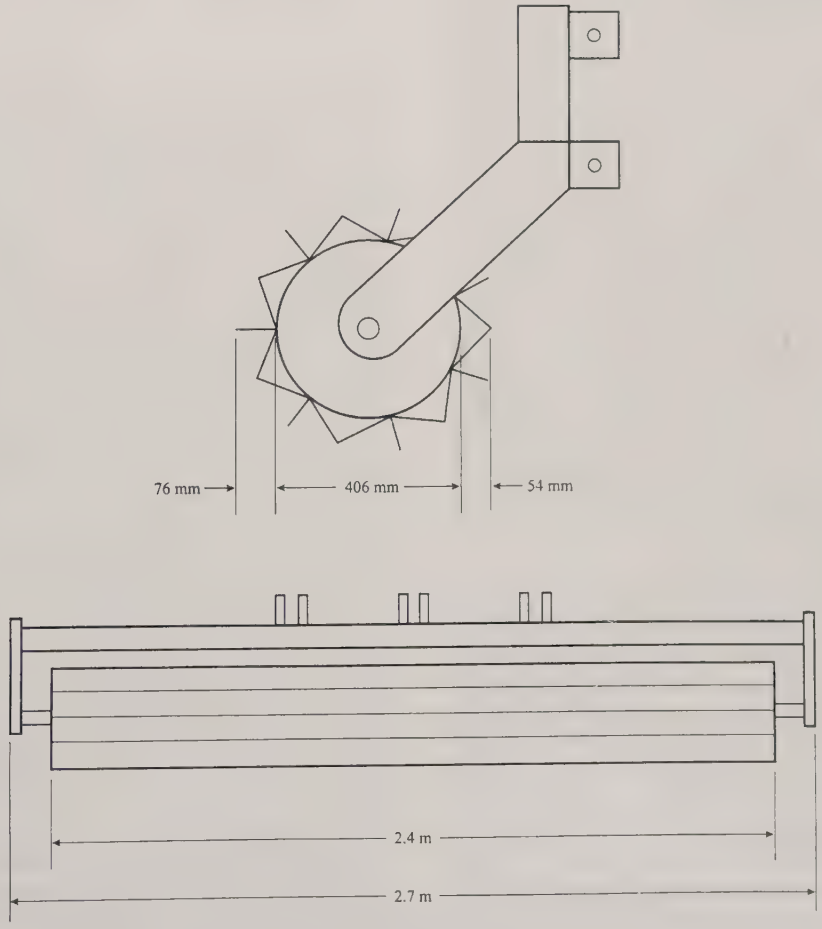

Figure 1. Schematic drawing of the roller-crimper used in this project. Inverted angle iron between blades dampens vibration and reduces blades cutting into soil.

significance was used. No significant site interactions were observed for cover-crop biomass, percent kill or soil water content, therefore these data for the 1999 season are presented averaged over both sites. Significant site interactions for weed biomass and cover-crop C:N ratio were observed, and these data were analyzed and are presented separately by site for 1999. Simple linear regression and correlation analysis were performed to establish relationships between variables.

Results and Discussion

Cover-crop biomass production

In 1999, a significant cover crop × growth stage interaction occurred for cover-crop biomass (Table 1). Rye and wheat biomass increased significantly through the soft dough growth stage; maximum biomass for rye and wheat at soft dough were 9.5 and 10.5 Mg ha^{-1}, respectively. However, black oat reached maximum biomass of 8.6 Mg ha^{-1} at anthesis. Attaining maximum biomass at an earlier growth stage may be beneficial, as it would allow greater residue production at an earlier planting date for a cash crop. Biomass production by black oat was significantly lower than that of rye and wheat in 1999. This is likely the result of extreme and unusually low temperatures during early development of the crop; early January temperatures were as low as –10°C. Freeze injury symptoms were observed at both sites and some winter kill occurred in black oat during this time. Similar observations on cold tolerance of this species were made by Reeves et al. (1997) and Bauer and Reeves (1999).

Both growth stage and cover crop significantly affected biomass in 2000, but there were no significant interactions among cover crop and growth stage treatments (Table 1). All cover crops reached maximum biomass at the early milk growth stage. Wheat showed significantly lower biomass production, with a maximum biomass of 7.7 Mg ha^{-1}. Rye and black oat achieved higher maximum biomass (10.7 and 10.8 Mg ha^{-1}, respectively). These two crops also achieved a high amount of biomass by anthesis, which, as noted in the previous year's results, would allow for earlier termination and therefore an earlier planting date of a succeeding summer cash crop.

The differences observed in biomass production can be attributed, at least in part, to the selective use of the crop. Black oat was bred for use as a cover and forage crop to produce greater residue amounts, while most varieties of rye, and especially wheat, have been bred as grain crops. Thus wheat produces a greater percentage of the maximum biomass as grain, not as stems (residue).

Cover-crop C:N ratio

The C:N ratio of cover crops serves as an important indicator of the decomposition rate of residue and resulting amount of soil coverage (Ranells and Wagger, 1996; Reeves,1994; Wagger, 1989). The relatively high C:N ratio of cereal cover crops can also be a disadvantage due to increased nitrogen immobilization (Doran and Smith, 1991; Reeves, 1994; Somda et al., 1991). In 1999, there were significant site × cover crop × growth stage and site × cover crop interactions for C:N ratios of cover crops (Table 2). Thus, sites will be discussed separately. The significance of site may be attributed to differences in available soil N and prior uses of the plot areas at each site. Wagger and Mengel (1988) found that the N content of small-grain cereals depends on available soil N.

On the Compass loamy sand, a significant cover crop × growth stage interaction was observed. Black oat showed no significant increase in C:N ratio from anthesis to the soft dough growth stage (38:1 and 39:1, respectively). Wheat had no significant changes in ratio from flag leaf to anthesis (32:1 and 31:1, respectively). Rye followed the expected trend of increasing ratio with increasing maturity (flag leaf 24:1, anthesis 34:1, and soft dough 64:1). The high C:N ratios of small-grain cover crops can be a disadvantage when N is immobilized (Doran and Smith, 1991; Reeves, 1994; Somda et al., 1991). By delaying kill time, there is an increase in potential for N immobilization. This was especially important with rye, which had very high C:N ratios at the last growth stage.

A significant cover crop × growth stage interaction for C:N ratios was also observed on the Cahaba sandy loam in 1999. The C:N ratios of all cover crops increased with maturity. Black oat and wheat increased C:N ratios from

Table 1. Cover crop biomass production (dry weight Mg ha^{-1}) by year, cover crop and growth stage for 1999 and 2000.

Cover crop	Growth stage	Biomass (Mg ha^{-1}) 1999[1]	2000
Black oat			
	Flag leaf	3.9	7.1
	Anthesis	8.6	10.0
	Early milk	–[2]	10.8
	Soft dough	7.8	–[2]
Rye			
	Flag leaf	4.9	6.9
	Anthesis	7.2	9.9
	Early milk	–[2]	10.7
	Soft dough	9.5	–[2]
Wheat			
	Flag leaf	4.9	3.6
	Anthesis	7.2	6.5
	Early milk	–[2]	7.7
	Soft dough	10.5	–[2]
$LSD_{(0.10)}$ growth stage within cover crop		1.33	1.40 (ns)
$LSD_{(0.10)}$ growth stage		0.77	0.81
$LSD_{(0.10)}$ cover crop		0.70	0.68

[1] Data averaged over two sites.
[2] Data not taken at this growth stage.

Table 2. Cover crop C:N ratio by year, site (soil type), cover crop, and growth stage for 1999 and 2000.

Year Site (soil type)		1999 Cahaba	1999 Compass	2000 Compass
Cover crop	**Growth stage**	**C:N ratio**		
Black oat				
	Flag leaf	21	23	27
	Anthesis	34	38	37
	Early milk	–[1]	–[1]	37
	Soft dough	45	39	–[1]
Rye				
	Flag leaf	21	25	26
	Anthesis	25	35	44
	Early milk			56
	Soft dough	48	64	–[1]
Wheat				
	Flag leaf	23	32	23
	Anthesis	32	31	31
	Early milk	–[1]	–[1]	36
	Soft dough	37	45	–[1]
$LSD_{(0.10)}$ growth stage within cover crop		7.1	6.2	4.9
$LSD_{(0.10)}$ cover crop		4.1	6.0	3.9

[1] Data not taken at this growth stage.

flag leaf through soft dough, while rye increased only from anthesis (25:1) to soft dough (48:1).

In 2000 on the Compass loamy sand, a cover crop × growth stage interaction was observed. Rye and wheat C:N ratios increased linearly with growth stage (Table 2). The C:N ratio did not significantly increase after anthesis in black oat (37:1 at anthesis and early milk), similar to the previous year at this site. The ratios measured were relatively consistent with those of other studies (Bauer and Reeves, 1999; Reeves, 1994; Wagger, 1989).

The ratios varied greatly across site-years, cover crops and growth stages, making it difficult to interpret data for consistent trends. However, rye was identified as having the greatest C:N ratio at the most mature growth stages (Feekes' 10.54 and 11.2). Black oat and wheat were similar in C:N ratio at these stages and were consistently lower than rye. Bauer and Reeves (1999) saw similar results in their study, where rye averaged higher ratios than those of oat, wheat and black oat. An increase in C:N ratio of rye was also shown by Wagger (1989) when two termination dates were compared.

Percent kill

A linear relationship between plant moisture content and visual percent kill ratings was observed in 1999 ($r^2 = 0.56$, $P \leq 0.01$) and 2000 ($r^2 = 0.52$, $P \leq 0.01$), validating use of visual ratings. Measurements taken at 28 days are presented for brevity and consistency in correlation to plant moisture content. However, it should be noted that after 14 days there were no significant increases in percent kill at any site-year.

A significant cover crop × growth stage × kill method interaction was observed (Fig. 2). At flag leaf, the label rate of paraquat and the one-half label rate paraquat + roller-crimper combination had a significantly lower kill mean, especially on black oat (26 and 28%, respectively), than glyphosate treatments. The roller-crimper alone was not able to effectively kill plants at flag leaf (13%, 16%, and 26% termination for black oat, rye and wheat, respectively). At flag leaf, cover-crop plant height was relatively low and plant stems were still elongating. At anthesis, the label rate of paraquat and the one-half label rate paraquat + roller-crimper combination were as effective (mean 93% kill) as the glyphosate treatments. Roller-crimper efficacy increased at anthesis to an average of 81%, but this is still significantly less effective than chemical and combination treatments at this growth stage. At anthesis, the roller-crimper was most effective on black oat (88%) compared to wheat (81%) and rye (74%). By soft dough, all kill methods were equally effective due to accelerating plant maturity and senescence (95% mean kill across all cover crops and kill methods).

At anthesis and soft dough, a combination of the roller-crimper and a half rate of either herbicide performed just as well as the herbicides alone at the label rate. The 1999 data indicated that the critical period lay between the anthesis and soft dough growth stages. During 2000, the last growth stage tested was changed to refine the most effective time to use the roller-crimper method.

In 2000, a significant cover crop × growth stage × kill method interaction was observed, similar to the previous year (Fig. 3). At the flag leaf growth stage, the effectiveness of the roller-crimper was low, with a kill mean of only 16% across all cover crops. Roller-crimper efficacy increased at anthesis to 85%. However, waiting until early milk (usually only 7–10 days after anthesis) resulted in 93% effectiveness by the roller-crimper; the average effectiveness of all other treatments was 95% when averaged over cover crops.

The full rate of glyphosate had equal kill effectiveness on all cover crops at all growth stages, averaging 95%. With the exception of wheat at the flag leaf growth stage, where kill was 49%, glyphosate at one-half label rate in combination with the roller-crimper had equal kill at all growth stages across all covers (averaging 95%). Paraquat at the full label rate was more effective at the flag leaf stage on rye (94%) compared to wheat (81%) and black oat (80%). Similar results were obtained with the one-half label rate paraquat + roller-crimper combination, where it was more effective on rye (88%), than on black oat (61%) and wheat (51%).

There were a few distinguishable similarities across all site-years. In both years it was shown that the flag leaf stage was too early to get an effective kill by using the roller-crimper alone. By anthesis, the one-half label rate + roller-crimper combinations were as effective as the label rate of either chemical used alone. By waiting the additional 7–10

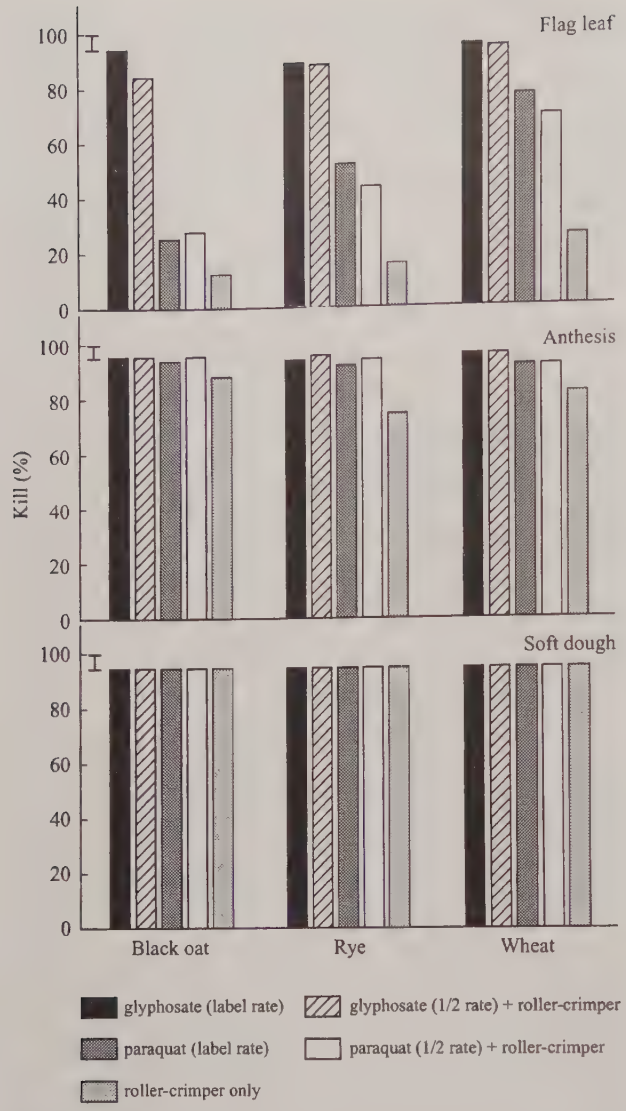

Figure 2. Percent kill 28 days after treatment by cover crop, growth stage and kill method during 1999. (Vertical bars denote $LSD_{(0.10)}$ kill method within growth stage by cover crop = 6.2%.)

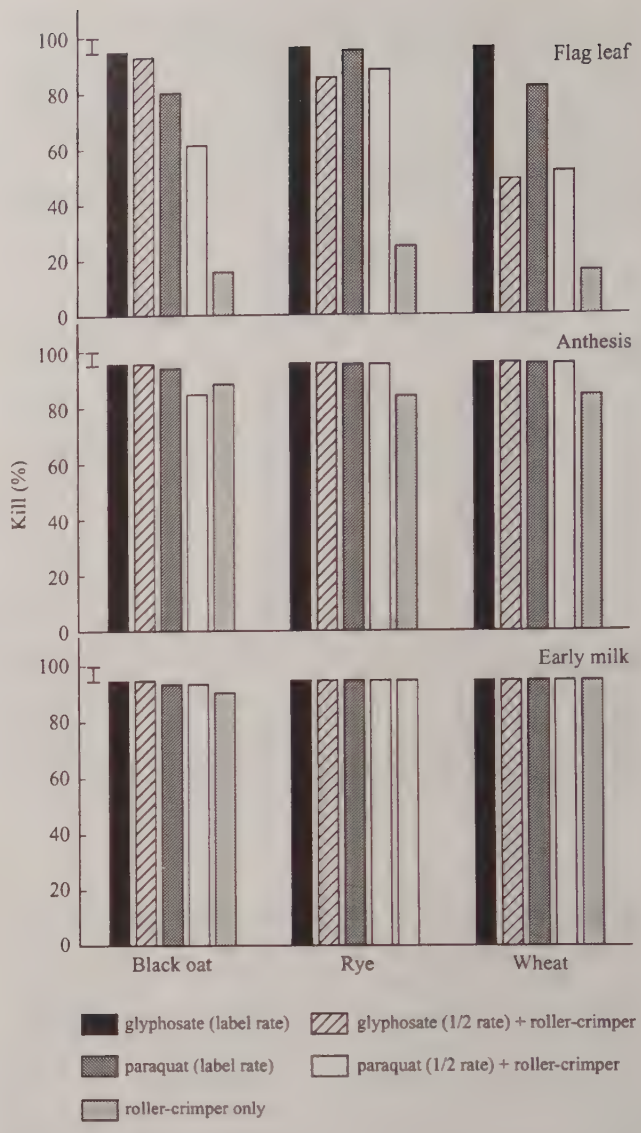

Figure 3. Percent kill 28 days after treatment by cover crop, growth stage and kill method during 2000. (Vertical bars denote $LSD_{(0.10)}$ kill method within growth stage by cover crop = 7.1%.)

days after anthesis to early milk (or later to the soft dough growth stage), we found complete kill of all three cover crop species with use of the roller-crimper alone.

Soil water conservation

There were no significant site interactions in 1999 for soil water, despite small differences in soil texture, so results are averaged across both sites (Fig. 4). For reference, volumetric water content at field capacity is typically about 100 g kg^{-1} (10%) and 123 g kg^{-1} (12.3%) and permanent wilting point (PWP) is 50 g kg^{-1} (5%) and 58 g kg^{-1} (5.8%) for a sandy loam (Cahaba soil) and loamy sand (Compass soil), respectively (Miller and Donahue, 1990).

A significant cover crop × growth stage × kill method interaction was observed during 1999 (Fig. 4). Soil water content measurements at the flag leaf growth stage were directly related to efficacy of kill method. Ineffective kill methods resulted in depletion of soil water by the still-growing cover crops. A significant linear relationship was observed between percent kill (visual ratings) and soil water content (r^2 = 0.37, $P \leq 0.01$); as percent kill increased, soil water increased. Glyphosate treatments, which resulted in the best kill, had the highest soil water content for all cover crops at flag leaf (111 g kg^{-1}). However, in wheat, soil water following paraquat treatments (95 g kg^{-1}) was not significantly different than soil water when wheat was treated with glyphosate (114 g kg^{-1}). Paraquat treatments were especially ineffective at terminat-

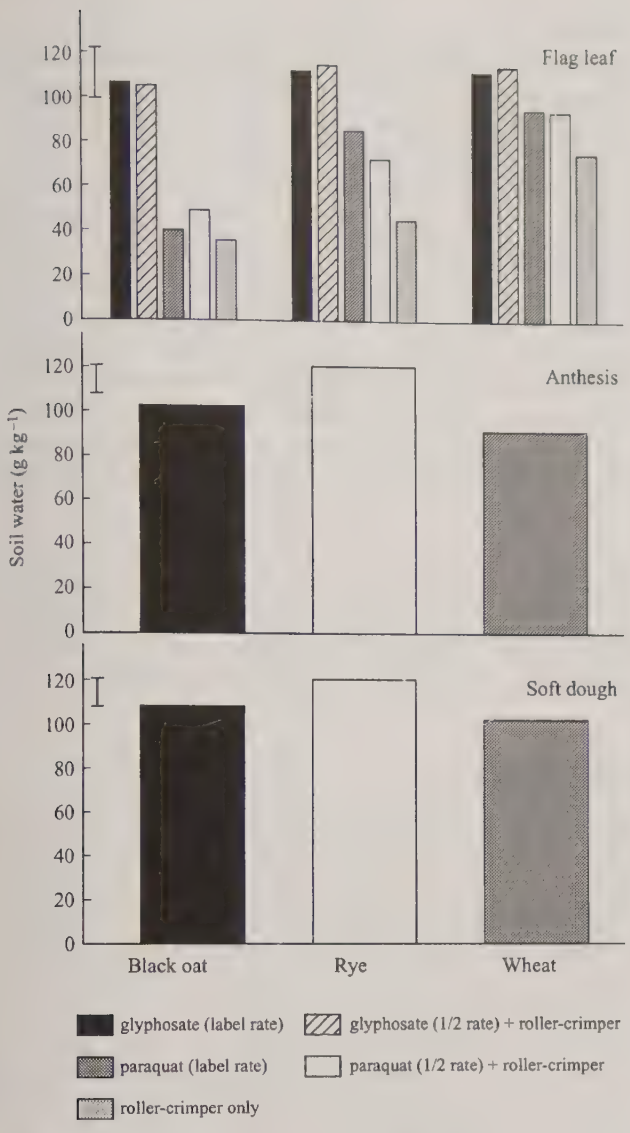

Figure 4. Soil water 28 days after treatment by cover crop, growth stage and kill method during 1999. (Vertical bars denote $LSD_{(0.10)}$ kill method within growth stage by cover crop = 20.3 g kg^{-1} and $LSD_{(0.10)}$ cover crop within growth stage = 15.3 g kg^{-1}.)

ing black oat, resulting in soil water depletion significant enough to likely affect emergence of a cash crop (45 g kg^{-1}). At flag leaf, the roller-crimper only treatment was the least effective kill method and therefore resulted in the lowest soil water content in all cover crops (50 g kg^{-1}). Considering the average PWP of the soils at both sites (54 g kg^{-1}), soil at this water content would not be adequately moist enough to plant a cash crop.

In 1999, there were no significant differences in soil water 28 days after treatment for any cover crop as a result of kill method at the anthesis or soft dough growth stages (average over all treatments was 103 g kg^{-1}). The lack of significant difference in soil water between kill methods was the result of high kill efficacy at these two growth stages. Although the roller-crimper efficacy was significantly lower than all other methods for all cover crops at anthesis, the soil coverage provided by the residue mat created by the roller-crimper resulted in soil water conservation and similar soil water contents (94 g kg^{-1}).

When cover crops were killed at anthesis and soft dough, a significant but weak linear relationship was observed between cover-crop growth (biomass production) and soil moisture content ($r^2 = 0.11$; $P \leq 0.01$). When killed at anthesis, rye resulted in greater soil water (118 g kg^{-1}) than either black oat or wheat (100 and 90 g kg^{-1}, respectively), but rye biomass (7.2 Mg ha^{-1}) was less than, or equal to, that of black oat (8.6 Mg ha^{-1}) and wheat (7.2 Mg ha^{-1}) at this growth stage. When killed at soft dough, soil water within wheat (100 g kg^{-1}) was less than under rye or black oat (120 and 110 g kg^{-1}, respectively). Wheat reached maximum biomass at the soft dough stage mainly due to its high harvest index. This resulted in less straw to provide soil coverage and may account for the lower soil water. However, these soil water contents were all near field capacity and would be ideal for planting a cash crop in May. Early May is the normal planting window for cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.), the most popular cash crops in the region.

Severe water deficits existed during spring 2000, therefore soil moisture data taken after the flag leaf stage are not presented. There was no measurable rainfall between 24 April and 22 May when soil water measurements were taken for all plots, excluding those terminated at the flag leaf growth stage. The rainfall in April–May of 2000 (92 mm, 45 mm of which fell after 22 May when all sampling was complete) was severely deficient, compared to 1999 (147 mm) and the normal rainfall for these 2 months (232 mm). All measurements taken during anthesis and early milk growth stages showed values not suitable for planting a cash crop (all values were below the PWP of 58 g kg^{-1} for a Compass loamy sand). Measurements taken from plots terminated at the flag leaf stage reflected the results of the previous season, with the amount of soil water being related to kill efficacy. The glyphosate and paraquat alone treatments and the one-half label rate glyphosate + roller-crimper combination, which resulted in the best kill means, had the highest soil water content for all cover crops at flag leaf (101, 82 and 84 g kg^{-1}, respectively). The roller-crimper alone was the least effective kill method at the flag leaf growth stage and consequently resulted in a soil water content (averaged over all cover crops) of 47 g kg^{-1}, which is below the PWP of 58 g kg^{-1}.

It is suggested, due to the results of the first season of this study, that kill should take place after anthesis, as this stage exhibited good kill efficacy, reduced water uptake by plants prior to cash-crop planting, and provided sufficient biomass to provide soil coverage. The use of a roller-crimper can also be recommended when killing after anthesis, due to water conservation benefits that occur due to increased soil coverage provided by the residue mat created by the roller-crimper. Blevins et al. (1971) and Munawar et al. (1990)

showed the benefit of cover-crop residue to conserve soil moisture, by decreasing evaporation and runoff, as well as increasing the ability of soil to store moisture.

Weed biomass

The two dominant weed species observed at both sites and both growing seasons were cutleaf evening primrose (*Oenothera laciniata* Hill) and wild mustard [*Brassica kaber* (D.C.) L. Wheeler]. In 1999, weed biomass was highly variable (c.v. 292%), with values so low (averaging 0.05 Mg ha^{-1}) as to have little practical significance. During 2000, the amount of weed dry matter produced was 0.02 Mg ha^{-1}, averaged over all factors, which holds little practical significance, and the results, similar to the previous season, were highly variable (c.v. 186%).

Although there were significant treatment effects, the high variability makes them difficult to understand. In general, the overall effect on weed biomass was related to amount of residue present, which, in turn, was related to growth stage and delayed kill of the cover crop. By delaying termination, residue increased in biomass, increasing the amount of soil coverage and weed shading. This delay also resulted in an increased C:N ratio of the residue, slowing the rate of decomposition and providing longer-lasting soil coverage for weed suppression.

Conclusions

This study shows that it is possible using a roller-crimper to effectively terminate cereal cover crops with reduced herbicide inputs. When termination occurs at early milk (Feekes' 10.54) or later, the use of herbicides may be eliminated. At this stage, all kill methods were equally effective (94% across all cover crops). There were no significant differences between cover crops in terms of percent kill when the roller-crimper was used; the main determining factor was growth stage. As a mechanical alternative to herbicides for killing cover crops, energy requirements for operation of a roller-crimper are estimated to be one-tenth that of a rotary mower. Energy coefficients for paraquat (493 MJ kg^{-1}; Ess et al., 1994) and glyphosate (454 MJ kg^{-1}; McLaughlin et al., 2000) are similar. Using the roller-crimper at anthesis in combination with one-half label rate of either of these herbicides would, of course, reduce the energy required to kill a small-grain cover crop. However, we emphasize that the roller-crimper is designed for use in no-tillage systems. Although no-tillage systems may require more energy for herbicides, less is required for machinery, fuel and labor, and total system energy requirement is less with no-tillage than for conventional tillage (Clements et al., 1995; Ess et al., 1994). Based on operating costs for a similar type implement (cultipacker), the use of a roller-crimper costs \$3.73 ha^{-1}, which is significantly less than herbicide treatments alone (\$29.64 ha^{-1} for glyphosate and \$25.16 ha^{-1} for paraquat at current prices and label rates) when variable costs are compared (Prevatt et al., 2001). Risk-averse farmers could use one-half label rate + roller-crimper combinations after anthesis, while organic farmers may benefit by delaying kill until early milk or later and eliminating all chemicals. Producers should note, however, that use of a herbicide in a manner inconsistent with the label is technically a federal violation. Therefore it will be necessary for herbicide manufacturers to adjust labels to address use with roller-crimpers. We have observed that no-till planting in the same direction as the cover crop was rolled facilitates seed–soil contact and reduces residue hair-pinning. Use of the roller-crimper provides additional benefits while killing cover crops, as it lays residue flat on the soil surface, providing maximum soil coverage, thereby preventing erosion, decreasing soil water evaporation and providing weed control.

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Entrepreneurial outcomes and enterprise size in US retail farmers' markets

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Abstract. *Recent studies have suggested that farmers' markets are increasingly important contributors to the economic development of rural and urban communities in the US. Yet, little is known about the specific ways and the extent to which farmers' markets contribute to developing their vendors' capacities as entrepreneurs or affect vendors' business success. In this study, we examine the capacities of farmers' market vendors in three states—New York, Iowa and California—and associated entrepreneurial outcomes. In particular, we explore how vendors' business activities and capacities are associated with different sizes of enterprises. A mail survey of up to 400 vendors, from 20 markets in each state, was conducted in 1999 to examine factors associated with business outcomes and vendor capacities. The importance of farmers' markets to small-, medium- and large-size enterprises and the particular contributions that have been most helpful to vendors were identified. Small-scale enterprises are still the most numerous at farmers' markets, making up almost 56% of all vendors. More than half of these enterprises are operated by part-time farmers or market gardeners. We found that the small enterprises had both less business and market experience, and sell at markets closer to home than do medium and large enterprises. Although these vendors with small enterprises have engaged in fewer entrepreneurial activities, made fewer business contacts and acquired fewer skills at farmers' markets, compared to medium and large enterprises they were more likely to consider farmers' markets to be their most important business development opportunity. Although, for these small enterprises, participating in farmers' markets may not yield financial gains as large as those gained by medium- and large-scale vendors, farmers' markets may be one of the few options for entrepreneurs to maintain and/or enhance their market niche in a community. Key information needs of small-, medium- and large-size enterprises are described, as well as suggestions for ways in which local educational institutions, Cooperative Extension, government agencies and nonprofit organizations can help support these enterprises and enhance community economic development in their regions.*

Key words: direct marketing, entrepreneurship, family farms, locally grown food, rural development, small farms

Introduction

Published studies suggest that farmers' markets are increasingly important in the economic development of rural and urban communities in the US (Gale, 1997; Lyson et al., 1995). In particular, farmers' markets create direct markets for agricultural products, value-added goods and crafts, generating marketing opportunities that can help maintain family farm businesses and promote new enterprises. They also link farmers to a variety of local institutional buyers and to customers for related on-farm activities, enabling farmers to diversify their marketing 'portfolios'. Some of these on-farm activities include U-picks, farm tours, farm festivals, petting zoos and other agritourism ventures (Alcantara, 1999; Feenstra and Lewis, 1999; Gale, 1997; Govindasamy et al., 1998a, b; Hilchey et al., 1995; Lyson et al., 1995).

Farmers' markets benefit residents of the communities in which they are located by providing access to fresh, locally grown produce and other agricultural products direct from producers, and creating a connection for many with the regional rural landscape and economy. Many markets are outlets for certified organic and specialty food and other agricultural products that may not be widely available in conventional markets. Just as important, farmers' markets provide social contexts that link producers and consumers, giving 'faces' to each in a larger economy characterized increasingly by indirect and impersonal connections (Abel et al., 1999; Bruhn et al., 1992; Lockeretz, 1986; Sommer, 1981). These linkages may even revive the appreciation and sympathy that many nonfarmers now lack regarding farmers (Lyson, 1986).

As the rising global economy continues to threaten the existence of many small farmers and ranchers (USDA,

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1998), income from farmers' market sales makes an important contribution to the stability of a growing number of family farm enterprises (Moline, 1997; Simon, 2000). The current food and agricultural system that dominates the North American market, with its rising input costs and declining commodity prices, is making it more difficult for small farmers to make ends meet (Heffernan et al., 1999). Farmers' share of the food dollar has shrunk to 20 cents out of every retail food dollar spent, while the marketing share has increased to 80 cents (Elitzak, 2000). Consequently, small farmers must find new, alternative marketing niches for their products if they are to remain in farming.

Although farmers' markets are recognized as important marketing outlets for small-scale farmers and other vendors, little is known about the specific ways, and the extent to which, farmers' markets contribute to the development of their vendors' capacities as entrepreneurs or affect their entrepreneurial or business outcomes. Neither is it understood how the size of a vendor's enterprise affects entrepreneurial outcomes. Hilchey et al. (1995) call entrepreneurial development the 'business incubation' function of farmers' markets. They found that farmers' markets in New York state enhanced business opportunities by promoting business start-ups, facilitating product development and diversification, creating opportunities to add value, and expanding the size and diversity of vendors' customer base as well as sales and income. Farmers' markets fostered business skills and entrepreneurship because they gave vendors an opportunity for learning business management, marketing, communication and leadership skills. Positive impacts for farm families included additional family income, learning for children, jobs for family members and reduced government assistance. Farmers' markets contributed to the economic development of communities through new jobs, and generating additional incomes and tax revenues through capturing a greater proportion of local and tourist dollars. Through enhancing income for small, local farmers, farmers' markets help to revitalize farms and preserve farmland.

To understand the role that farmers' markets have in creating and sustaining new rural enterprises and business outcomes for their vendors, a tri-state study of farmers' markets in New York, Iowa and California was launched in the summer of 1998. These three states lead all others in the number of farmers' markets they have. California had 340 farmers' markets, New York 228, and Iowa 126 according to the US Department of Agriculture (USDA, 2000). The study included farmers' markets from three different regions of the country with different agricultural, economic and social contexts, to obtain a fuller picture of the entrepreneurial activity nationwide.

New York, a Rustbelt state—one of the northeastern and north central states which were once vibrant centers of traditional manufacturing—has both declining industrial and agricultural sectors. Agriculture has been changing rapidly, leading to conditions under which producing major commodities such as corn (*Zea mays* L.), soybeans (*Glycine max* L.), and milk and meat tends to be unprofitable because of limited market opportunities and comparative disadvantages in the global food economy (Gillespie et al., 1994). The fruit and vegetable and food manufacturing sectors have also been in decline. However, New York also includes major population centers that now rely mainly on food imported from out of state, in part due to the seasonality of agricultural production in New York. Affluent consumers, mainly from these urban centers, are increasingly concerned about the freshness and healthfulness of their food and are beginning to value foods produced more locally. Others, many from immigrant groups, desire foods important to their ethnic cuisines that may not be readily available through the conventional commercial food system. These conditions create new opportunities for farmers' market vendors to produce and sell fresh foods, organically grown foods, ethnic foods and other local specialty items.

In contrast to New York, California, a Sunbelt state, has many more large-scale farms and is prominent nationally in fruit and vegetable production. Due to its agro-climatic conditions, the growing season in California is virtually year-round, especially where irrigation water is available. California also has several major population centers; i.e., the Bay Area and Los Angeles Basin, where affluent consumers show growing concern about food quality, freshness and healthfulness. In addition, it has major and growing Latino and Asian populations, each with distinct food preferences. As in New York, these conditions generate opportunities for farmers' market vendors to produce and market very fresh, certified organic and local specialty foods unique to California.

Iowa, a Cornbelt state, is a leader in producing many of the country's conventional commodities, such as corn, soybeans and pork. Although historically significant, commercial production of fruits and vegetables is currently a minor component of the state's agriculture. As with New York, the agro-climatic conditions only permit seasonal production. Iowa has fewer and smaller major metropolitan areas than New York or California, and thus a smaller base of affluent, urban consumers. The rural population in Iowa remains significant, but is changing. While farm population has sharply decreased, nonfarm rural residents are increasing. Overall, Iowa is ethnically more homogeneous than either New York or California, so ethnic food interest and opportunities are not as abundant. Public concern about the quality and healthfulness of foods in the conventional commercial food system is growing, but is not yet widespread. Iowa's circumstances provide an interesting contrast to New York and California and offer different insights about what makes farmers' markets successful in rural development.

This article reports on the results of a vendor survey conducted in New York, Iowa and California, focusing on vendors' entrepreneurial outcomes and capacities at farmers' markets. In particular, we explore how vendors'

entrepreneurial activities and capacities are influenced by the sizes of their enterprises. We also examine the importance of the farmers' market to small-, medium- and large-size enterprises and identify particular types of assistance that have been most helpful to vendors. Key skills and information needs of small-, medium- and large-size enterprises are identified, as well as suggestions for ways in which local educational institutions, cooperative extension, government agencies and nonprofit organizations can help support these enterprises and enhance community economic development in their regions.

Entrepreneurship and Enterprise Size

Entrepreneurship is a topic of growing interest to both business practitioners and social scientists. Scholarship in the US after the Second World War focused not so much on understanding the process of entrepreneurship, but rather on specifying the individual characteristics—psychological and cultural—of entrepreneurs. In the past decade, however, research on entrepreneurship has turned away from an emphasis on the fixed traits of individual entrepreneurs to concern with specific entrepreneurial activities and the social context that makes them possible (Gartner, 1989). This new approach recognizes that entrepreneurship is often situational, and thus may be more or less enhanced by the organizational structure, socio-economic characteristics of the surrounding community, relations with other local economic institutions, or specific government policies and programs (Bryant, 1989; O'Farrell, 1986).

Cooper et al. (1989) studied the impact of the initial size of firms on entrepreneurship. The focus was whether smaller start-ups differed from larger ones in the backgrounds of the entrepreneurs, their processes of starting or the subsequent patterns of development. They found that entrepreneurs in larger firms tended to have the backgrounds necessary to assemble more resources, had more education, more management experience, more managerial goals and were more likely to have partners. They relied more on external investors and started ventures that were more closely linked with previous jobs. The larger firms tended to seek professional advisors more than informal sources of information. Women tended to be associated more often with the smaller ventures. Although both large and small firms reported high growth rates, the smaller ones had higher percentage growth rates and increases in employment. Characteristics of the surviving firms (those that did not go out of business) were that the entrepreneurs were ready to experiment, to change and to learn from their experiences. Although the larger firms had some advantages, the study concluded that 'the growth of the smaller start-ups suggests that even those ventures that appear to have few resources and modest potential can, in the aggregate, contribute substantially to the economy' (Cooper et al., 1989, p. 318).

In a study of enterprise size and business development benefits in the southeastern US, Green (1994) found that medium-scale firms tended to generate more benefits than smaller firms. For example, they had better employment arrangements, more minorities were hired and there was greater adoption of new technologies. So, although small enterprises may have advantages in terms of greater flexibility, the literature suggests that they may be undercapitalized and may have fewer human and social capital resources.

Do small-scale farmers and vendors that attend farmers' markets follow the same patterns as these small firms? Are there analogous differences based on enterprise size? Farmers' market and other direct marketing vendors have been compared according to enterprise size by others (Gale, 1997; Lyson et al., 1995; Vaupel, 1985). In terms of market share, as in the conventional agriculture and marketing system, the largest direct marketing enterprises tend to benefit the most. Vaupel (1985) found, in a study of California direct marketing farmers, that 'the largest percentage of the product is supplied by the largest farms' (p. 6), with almost 20% of direct marketing sales coming from farms with annual sales of US$500,000 or more. High percentages (about 12–20% in each sales category) also came from farms with annual gross sales of $250,000 to $499,999 and $100,000 to $249,999. Gale (1997) found that for direct-marketing farmers nationwide, 'the midsized and larger farms that sell directly do so in larger quantities' accounting for 'nearly half of direct sales' (p. 21). These studies and others are consistent in showing that as enterprise size increases, so does total direct sales. However, they speak little about the actual entrepreneurial or business development process in which farmers are engaged.

There is evidence that small-scale farmers and other businesses are using multiple marketing channels and even new nonfarm activities to diversify (Carter, 1999; Gale, 1997; Govindasamy et al., 1998b; Hilchey et al., 1995; Simon, 2000). Diversification itself can be seen as an entrepreneurial practice (Nórthdurft et al., 1986). The small firms research literature calls the practice of adding additional, distinct enterprises, 'portfolio entrepreneurship'. Carter (1999) found that for small farmers in Cambridgeshire, England, multiple business interests and additional business activities make a substantial contribution to both the numbers of enterprises and to employment creation. Many of these new enterprises arise from the original firm, and owners tend to make little distinction between them and the primary farming enterprise. The new forms of diversification include activities such as direct retailing, food processing, recreation and new crops. Carter (1999) concludes that, 'The contribution of farmers to rural business development can be seen not only in the operation of their farm businesses, but also in their ability and propensity to start additional enterprises . . . In this respect, farms are emerging as centres of mixed entrepreneurial talent' (p. 427).

Farmers' markets, we suspect, are key institutions in promoting the concept and practice of 'entrepreneurship' in

US agriculture, particularly for the smallest of the enterprises. In particular, we hypothesize that the nature of entrepreneurial or business activities, and the extent to which vendors engage in these activities, will vary significantly, based on enterprise size. Further, we hypothesize that the importance of farmers' markets, and the ways in which they help to incubate small farm businesses, will also vary with enterprise size. The differences in 'entrepreneurship' we expect to see between large-, medium- and small-size vendors will suggest different strategies for outreach and extension to support these vendors.

Study Population and Data Collection

This study is part of a larger project in which investigators interviewed 60 farmers' market managers in New York, Iowa and California. From these cases, we selected approximately 20 markets per state to represent the range of market situations in each state, proportionally stratifying the sample based on the state's distribution of rural, urban and metro markets. Lists of vendors' names and addresses were obtained from the market managers of each of the 20 markets. If a market had 20 or fewer vendors, we included all the vendors; if it had more than 20 vendors, we randomly sampled 20. In Iowa, where the great majority of markets are smaller than 20 vendors per market, more markets were selected.

The core of the vendor questionnaire used in each state was developed jointly in the winter of 1998/99 by project investigators, with advice from the respective statewide advisory committees comprised of market managers and others. Questionnaires administered in each state included six major sections: (1) basic characteristics about the vendors' enterprise, such as duration, experience, other marketing outlets, employment created; (2) vendors' views of the benefits and challenges of the particular farmers' market selected for the survey; (3) vendors' entrepreneurial activities and skills gained through their farmers' market experience and their future information needs; (4) vendors' financial characteristics; (5) vendors' background information; and (6) space for responding vendors to write comments and explanations. Because we asked many questions about the specific market from which the respondent had been selected for the sample, separate versions of the questionnaire that named that market were prepared for the vendors of each market.

Surveys were conducted by mail between March and November 1999 in all three states, using a modified Dillman (1978) approach. The specific procedures varied slightly across states. At a minimum, the initial contact involved a cover letter and questionnaire. This was followed by a reminder and thank-you postcard. Those still not responding after a month received another mailing of a cover letter and second copy of the questionnaire. The cover letters explained the study and its importance and requested the recipients' participation. To maintain anonymity of the vendors, the questionnaires were numbered and respondents were asked not to write their names on the questionnaires. Respondents mailed completed questionnaires to the investigators in each state. The number of cases and response rates for each state appear in Table 1. Completed questionnaires were then photocopied and sent to New York, where project staff coded and entered the data. Data from all three states were included for this paper. The SPSS statistical package was used for descriptive as well as multi-variate and regression analyses (SPSS Inc., Chicago, IL).

Size of enterprise: Gross enterprise sales

The estimated gross enterprise sales for each vendor was calculated by dividing gross sales from all retail farmers' markets by the percentage of total enterprise sales from all retail farmers' markets. We used this to estimate the size of a vendor's overall enterprise, some of which might involve sales in outlets other than farmers' markets.

The National Commission on Small Farms (USDA, 1998), defines a small farm, in general, as a farming enterprise with annual gross sales less than US$250,000. According to this definition, 91.8% of farms in the US qualify as small farms (USDA, 1997). Almost all of our cases (94%) are considered small farm enterprises by this definition. To examine the effects of size on different aspects of vendors, we grouped the 504 vendors for whom we could calculate gross enterprise sales into three categories: small—vendors with total gross income of less than US$10,000 (55.6%); medium—sales between US$10,000 and US$99,999 (31.7%), and large—sales of US$100,000 or greater (12.7%). Table 2 shows the distribution of small, medium and large vendors by state.

Large- and medium-scale vendors were much more common in California, while small-scale vendors were more typical in Iowa and New York. California is much

Table 1. Survey response rates for each state.

Item	California	Iowa	New York
Total eligible surveys distributed	375	368	220
Usable questionnaires returned	209	249	130
Response rate (%)	56	68	59

Table 2. Number of enterprises by size for each state.[1]

Enterprise category[2]	California	Iowa	New York	Total
Small	47 (27.0)	158 (75.6)	75 (62.0)	280 (55.6)
Medium	75 (43.1)	47 (22.5)	38 (31.4)	160 (31.7)
Large	52 (29.9)	4 (1.9)	8 (6.6)	64 (12.7)
Total	174 (100.0)	209 (100.0)	121 (100.0)	504 (100.0)

[1]Numbers in parentheses are percentage of total.
[2]In gross sales, small = less than US$10,000; medium = US$10,000–99,999; large = US$100,000 or more.

more equally distributed among small, medium and large vendors compared to Iowa and New York, in which small-scale vendors predominate, with the rest being mostly medium-scale vendors.

Results

The relationship between entrepreneurship and enterprise size will be examined in three sections. We first look at the overall entrepreneurial context of vendors; specifically enterprise type, history and current market participation. Then, we focus on entrepreneurial or business outcomes; that is, entrepreneurial activities and business skills and abilities. Finally, we'll look at whether there are any relationships between characteristics of vendors' enterprises, business skills and abilities and the extent of vendors' entrepreneurial activities.

Entrepreneurial context: Characteristics of the entrepreneurs at farmers' markets

Table 3 shows how the type of vendor relates to the size of the enterprise (Pearson chi-square = 136.43, $P < 0.001$). Not surprisingly, most of the full-time farmers were in the medium- and large-scale categories while most of the part-time farmers and gardeners were in the small-scale category. Most crafters and others were also in the small-scale category. Other data and personal interviews indicate that it is likely that these small-scale vendors had other employment in addition to their farmers' market enterprise or they were retired individuals using the farmers' market as a way to earn extra income.

Table 4 describes the business experience of vendors and the frequency and distance they travel to attend farmers' markets. The operators of larger enterprises tended to have more business experience, although the operators of large and medium enterprises were not statistically different in the number of years they attended farmers' markets. On the other hand, the large enterprises attended more market days and more markets per week. The large enterprises sold at more than nine markets per week (more than one per day), compared to an average of fewer than four markets per week for the middle category and about two markets per week for the small. The large enterprises were also more likely to travel longer distances to markets—an average of more than 80 km (50 miles) one way compared to a little more than 26 km (16 miles) for the smallest enterprises (Table 4).

Business outcomes: Entrepreneurial activities and skills

The degree to which vendors engaged in entrepreneurial activities since they began selling at farmers' markets varied by the type of activity. Almost two-thirds of all vendors had expanded existing product lines; for example, a vegetable vendor who added a new variety of pepper (*Capsicum* spp.). Almost 50% of all vendors had added a

Table 3. Vendor type in numbers by enterprise size.

	Enterprise size[1]			
Vendor type	**Small ($n = 280$)**	**Medium ($n = 160$)**	**Large ($n = 64$)**	**Total ($n = 504$)**
Full-time farmer	37 (13)[2]	88 (55)	44 (69)	169 (33)
Part-time farmer or gardener	146 (52)	41 (26)	8 (13)	195 (39)
Food business	27 (10)	21 (13)	6 (9)	54 (11)
Crafter or other	70 (25)	10 (6)	6 (9)	86 (17)

[1]In gross sales, small, less than US$10,000; medium, US$10,000–99,999; large, US$100,000 or more.
[2]Numbers in parentheses are percentages of total number (n) in each column.

Table 4. Business experience of vendors, and the frequency and distance they travel to attend farmers' markets (FM), by enterprise size.

	Enterprise size[1]			
Activity	**Small**	**Medium**	**Large**	**Total (average)[2]**
Years in business ($n = 478$)	7.2	14.2	22.0	11.4
Years at any FM ($n = 497$)	7.1	11.6	10.9	9.0
Number of market days in 1998 ($n = 464$)	18.8	27.6	36.5	23.9
Number of markets per week ($n = 499$)	2.0	3.6	9.4	3.4
Distance to market in km (miles) ($n = 500$)	27.0 (16.8)	56.2 (34.9)	83.9 (52.1)	43.5 (27.0)

[1]In gross sales, small = less than US$10,000; medium = US$10,000–99,999; large = US$100,000 or more.
[2]All means in a row are significantly different at $P < 0.05$ as determined by F-statistic.

new product category; for example, a fruit vendor added baked goods. Forty percent had made new business contacts through the farmers markets (e.g., with restaurants or stores). Fewer than a third of the vendors, on average, had engaged in the other entrepreneurial activities. For example, only about 25% of the vendors had begun additional processing to add value to their product, and only about 10% had developed a mailing list.

Vendors from different-sized enterprises varied in the kinds of entrepreneurial activities they had engaged in since they began selling at farmers' markets. Table 5 shows that the medium and large enterprises tended to engage in these entrepreneurial activities more than the small vendors. The exceptions are vendors who added new product categories, for which there was no significant difference by enterprise size.

We also examined whether the size of the enterprise is related to the number of different entrepreneurial activities a vendor engaged in. We found that there is a statistically significant relationship ($P < 0.05$), although it is not linear. The operators of small enterprises engaged in fewer activities (average of 1.89) than did those with medium (average of 2.56) and large enterprises (average of 2.68).

Table 6 describes the top five skills and abilities respondents said were improved by their farmers' market experience. For most of the skills, the operators of small enterprises indicated the least improvement, while the operators of medium- or large-scale enterprises indicated the most improvement. Business self-confidence and cooperating with other business people did not differ across the three sizes of enterprises. However, the skills having to do with customer relations and product marketing did vary among different-sized enterprises.

Relationship between experience, skills and entrepreneurial activity

The relationship between business experience, skills gained at the farmers' market and the likelihood of engaging in entrepreneurial activities by vendors of different sizes is complex. Although the operators of large enterprises tended to have more years of business and farmers' market experience, our data do not support the contention that experience alone will increase the likelihood of vendors engaging in more entrepreneurial activities. However, our data do show that farmers' market experience and skills gained at the farmers' market are weakly correlated. The number of markets per week and the number of entrepreneurial activities vendors engaged in since starting to sell at farmers' markets were also weakly correlated.

There are stronger correlations between certain skills (measured by higher scores) and the number of entrepreneurial activities vendors began since selling at farmers' markets. Improvement of pricing skills ($\beta = 0.170$) and merchandizing skills ($\beta = 0.132$) were statistically significant predictors of the number of entrepreneurial activities in a stepwise regression analysis, but the R^2 of 0.079

Table 5. Entrepreneurial activity by enterprise size (percent).

	Enterprise size[1]				
Activity	**Small**	**Medium**	**Large**	**Total**	**Significance[2] ($P < 0.05$)**
Added new product category ($n = 497$)	48	46	42	47	NS
Expanded existing product lines ($n = 497$)	60	75	74	66	0.002
Begun additional processing ($n = 497$)	20	29	42	25	0.001
Developed mailing list of farmers' market customers ($n = 497$)	6	13	18	10	0.005
Made new business contacts ($n = 496$)	26	56	60	40	0.000

[1]In gross sales, small = less than US$10,000; medium = US$10,000–99,999; large = US$100,000 or more.
[2]Statistical significance determined by F-statistic. NS, not significant.

Table 6. Farmers' market skills and abilities by enterprise size (mean scores on Likert scale 0–4).[1]

	Enterprise size[2]				
Skills (ranked by average mean scores)	**Small**	**Medium**	**Large**	**Total (average)**	**Significance[3] ($P < 0.05$)**
Customer relations improved ($n = 480$)	2.55	2.82	2.87	2.68	0.020
Business self-confidence improved ($n = 474$)	2.42	2.65	2.62	2.52	NS
Merchandizing skills improved ($n = 481$)	2.30	2.68	2.54	2.45	0.004
Pricing skills improved ($n = 489$)	2.26	2.54	2.49	2.38	0.021
Cooperating with business people ($n = 472$)	2.31	2.49	2.27	2.36	NS

[1]0 = low; 4 = high.
[2]In gross sales, small = less than US$10,000; medium = US$10,000–99,999; large = US$100,000 or more.
[3]Statistical significance determined by F-statistic; NS, not significant.

indicates that this model did not explain much of the variance. (The β coefficient measures the estimated impact on the number of entrepreneurial activities due to a change in one unit in pricing or merchandizing skills.) This suggests that farmers' markets provide opportunities to gain particular business skills that support the development of more entrepreneurial activities.

Importance of farmers markets to vendors' businesses

To get a clearer sense of the relative importance of farmers' markets to different-sized enterprises, we asked vendors to rank the three marketing venues that provided the greatest opportunity for the development of their businesses. Choices included the farmers' market from which we had surveyed them, all other farmers' markets, all other retail (e.g., roadside stands, from home, U-pick, Community Supported Agriculture (CSA), mail order), direct wholesale (e.g., direct delivery to restaurants, stores, schools, hospitals), wholesale, craft or art shows and other. Almost 80% of all vendors reported that farmers' markets (the surveyed market plus all others) provided the most important opportunity for business development. This was not only true for the small and medium enterprises, but also for almost half of the large enterprises. The surveyed farmers' market, often their only market, was reported as the most important opportunity for the small vendors. Table 7 shows how important farmers' markets are to their vendors, by enterprise size.

Information needs of vendors

To understand whether operators of different-sized enterprises have different information needs related to improving their entrepreneurial outcomes, we asked what kinds of information would be most useful. Overall, most vendors indicated that their farmers' market enterprises could be most improved with more information on two topics: (1) advertising, promotion and community outreach; and (2) improving their display, signage, packaging and labeling. Both have to do with marketing, first, to the larger community and second, to their immediate customers. The topics vendors were typically least interested in gaining information about were concerned with product development (e.g., post-harvest handling and production issues, developing value-added products, expanding product lines, improving product quality) and improving business skills. Again, operators of medium and large enterprises were more interested in obtaining marketing information than were those with small enterprises.

Discussion

Our findings indicate that farmers' markets are important for providing business development opportunities, promoting entrepreneurial activities, and enhancing the skills and capacities of vendors of all sizes. Results from this study, in addition to interviews with small-, medium- and large-scale vendors, suggest that the particular ways in which vendors benefit from farmers' markets vary, depending on the size of the vendors' enterprise. For the medium- and large-scale vendors, farmers' markets help them to expand or complement existing, well-established businesses. For small vendors, farmers' markets seem to function much more as incubators for new businesses and as the primary venues for part-time enterprises. The entrepreneurial activities of large and small vendors are similar, but the business contexts in which these occur are very different.

Although we have analyzed entrepreneurial outcomes and activities by enterprise size, we acknowledge that most of the large enterprises are in California, with only a small number of observations in Iowa and New York. Therefore, size and geography may be confounded, particularly for the large-size enterprises. Despite the limits to our data, however, we surmise that size is an important variable net of geography.

Business context and entrepreneurial outcomes for medium and large enterprises

As the literature suggests, operators of large enterprises tend to engage in more entrepreneurial activities. Additionally, more of the medium and large vendors indicated that the skills and abilities they need are improved by their participation at farmers' markets. As vendors participate in more entrepreneurial activities, they

Table 7. Most important opportunity for business development by enterprise size (percent).

	Enterprise size[1]				
Marketing outlet	Small	Medium	Large	Total	Significance[2] ($P < 0.05$)
Surveyed farmers' markets	67	33	2	48	0.000
All other farmers' markets	19	47	44	31	0.000
All other retail	6	14	12	9	0.015
Direct wholesale + wholesale	5	12	39	11	0.000
Craft/art show	2	3	2	3	NS

[1]In gross sales, small = less than US$10,000; medium = US$10,000–99,999; large = US$100,000 or more.
[2]Statistical significance determined by F-statistic; NS, not significant.

acquire more skills and confidence to improve, expand or diversify their enterprises.

Farmers' markets are helping these growers and other vendors maintain their market niches by adding value to their products through expanding existing product lines and through making new business contacts. The skills and abilities that they have gained in particular through farmers' markets include: improved customer relations, business self-confidence, and merchandizing and pricing skills. Medium-scale vendors benefitted significantly more than either small- or large-scale vendors in both merchandizing and pricing skills. This may reflect that they are at a particularly rapid stage of entrepreneurial learning and assimilation, whereas for large vendors, who have already acquired some of these skills, there is less room for improvement. Small-scale vendors, on the other hand, may not be at a 'fast growth stage' in their entrepreneurial development.

The growth paths of small-, medium- and large-scale vendors who attend farmers' markets, although not directly addressed in this study, would be a promising area for future research. We did not gather longitudinal data, which would be necessary for assessing the actual business trajectories of different growers and enterprises. Our informal observations suggest that although some small- and medium-scale vendors will expand their businesses using farmers' markets, many others will not, or may not, even want to grow. Our preliminary observations suggest that the 'small and stable' group may be the more dominant type of enterprise. It would be useful in future research to compare the decision-making and practices of this group to those of small- or medium-scale enterprises that grow significantly larger in the course of selling at farmers' markets.

Interviews with some of the medium- and large-scale growers (Podoll, 2000) show that they are using the farmers' market as 'testing grounds' to enter other markets. One grower, for example, takes advantage of the increasing tourist trade at the Davis Farmers Market in California to develop gift packaging for dried apricots, apricot products and nuts, as well as to help establish a new mail order business.

Information needs for medium and large enterprises

Operators of the medium enterprises and especially the large enterprises are interested in more information on advertising, promotion and community outreach primarily; and on information to help them improve their individual farmers market display and products, secondarily. A recent study of Pennsylvania farmers' market vendors found that farmers still do not have sufficient information about marketing opportunities (Farmers Market Trust and Regional Infrastructure for Sustaining Agriculture, 1999). Some market managers provide this information to interested vendors, or it is available at state and national farm conferences. According to one market manager of a large city market, relatively few vendors take advantage of these opportunities, but for those that do, their businesses have benefitted. Similarly, Cooperative Extension, growers' associations, farmers' market associations, and local economic development agencies may improve their effectiveness by working cooperatively to direct this kind of information to these vendors.

Business context and entrepreneurial outcomes for small enterprises

The small-scale enterprises are still the most numerous at farmers' markets, making up almost 56% of all the vendors. Over half were operated by part-time farmers or market gardeners. This group has had less experience in business in general and at farmers' markets in particular. They also attend fewer farmers' markets and tend to sell at markets closer to their farms. Although these vendors have engaged in fewer entrepreneurial activities, made fewer business contacts and acquired fewer skills at farmers' markets, they consider farmers' markets to be their most important business development opportunity. In fact, farmers' markets are more important to them as compared to the medium- and large-scale enterprises.

Interviews with small-scale vendors at the Laytonville Farmers Market, a rural market in Mendocino County, support these findings (Lewis, 2000). Several growers started their businesses at the farmers' market and used it as a 'training ground' to gain business and marketing experience, as well as exposure to launch new businesses. One vendor, for example, developed a new enterprise selling water plants in addition to the salad sprout business she already had at the market. As she became more knowledgeable and gained confidence, she began a consulting business on pond maintenance, and this has become her primary endeavor.

Small-scale vendors, especially those in rural areas, are faced with different challenges in starting and maintaining their business enterprises. Often, a farmers' market enterprise contributes only a small part of their overall household income. However, as our study and interviews show, farmers' market experience can be critical in promoting skills, and providing business experiences and an environment where vendors can start new enterprises or enrich existing ones. Although participating in farmers' markets may not yield financial gains as large as those of medium- and large-scale vendors, it may be one of the few options for entrepreneurs to maintain and/or enhance their market niche in a community.

Conclusions

Farmers' markets are very important in enhancing the business development experiences of vendors of all sizes, but this happens in different ways. They provide a setting where medium- and large-scale vendors can augment and

diversify their 'entrepreneurial portfolio'. Such diversification may provide a more stable foundation for the overall enterprise. Farmers' markets also contribute to the 'incubation' or 'start-up' of many small-scale vendors' enterprises. In other words, they provide a nurturing, relatively low-risk environment where new ventures can be launched on an initially modest scale. By promoting new, fledgling businesses and supporting longer-established ones, farmers' markets contribute to the economic development and vitality of both rural and urban communities from coast to coast in the US.

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The Origins of the Organic Movement. Phillip Conford. 2001. Floris Books, Edinburgh. 287 p. £14.99, ISBN 0–86315–336–4

In The Origins of the Organic Movement, Phillip Conford paints a picture of the beginnings and growth of the organic movement. Conford's work is detailed and, in some places, difficult to follow, yet immensely interesting. In the telling of his story, the author dashes much of the current beliefs about the beginnings of the organic movement, which is most often attributed to Lady Eve and Sir Alfred Balfour, or sometimes to Rudolf Steiner, or even to Rachel Carson. Conford carefully traces the historical underpinnings of the movement, and finds warnings about the perils of industrialized chemically based agriculture as early as 1914. The warnings suggested that reliance on chemical fertilizers was potentially dangerous and was at odds with the 'Rule of Return', which states that soil health and fertility is maintained by encouraging the presence of humus.

Conford places the date of the beginning of the organic movement at 1926. Several critical events occurred in different regions of the world during the 10 years prior to 1926. Albert Howard began working with composting in India. Richard St Barbe, in Africa, began working as a conservationist. Rudolf Steiner gave his lectures on agriculture, and his successor, Ehrenfried Pfieffer, carried on his work to begin the biodynamic movement. In 1926, the Peckman experiment, led by George Scott Williamson and Innes Pearse, worked from the premise that health was more than the absence of sickness. In great detail, Conford chronicles the contribution of these and others who were influential in the organic movement.

The third chapter attributes the beginnings of the organic movement to three English men—Sir Robert McCarrison, Sir Albert Howard and Richard St Barbe Baker—who learned many lessons from the 'peasants of India' beginning in the early 1900s. Sir Robert McCarrison was a nutritionist who studied the causes of health rather than causes of illness. The Sikhs, Pathans and Hunzas were the subject of his study, and they were remarkably free from heart disease, diabetes, cancer and other illness. After years of research on rats, McCarrison hypothesized that human illnesses were caused by poor nutrition. Sir Albert Howard, an agricultural scientist, through his extensive research in India on plant breeding and experimenting with feeding cattle from healthy soil deduced that 'the foundations of all good cultivation lie not so much in the plant as in the soil itself'. He developed a system of composting, the Indore Process, that later had a tremendous influence on the growth of the organic movement. Richard St Berbe, a forester who spent a large amount of time in Africa, was the founder of the Men of Trees Organization. All three returned to England in the mid-1930s. Their experiences in India and Africa shaped the criticism of Western agriculture which eventually gave rise to the organic movement.

The fourth chapter discusses Rudolf Steiner and biodynamic agriculture, which was developed in Germany in the early 1920s. Like the English scientists discussed in the previous chapter, Steiner believed there was a link between how food was grown and the health of the people consuming the food, so soil quality was integral to producing high-quality food. In contrast to others, Steiner's ideas about agriculture had a strong esoteric component, as evidenced by his belief there was a relationship between food production and the Cosmos (for example, he suggested sowing plants in keeping with the phases of the moon). Soil fertility and composting techniques were an important part of biodynamic agriculture, and were further developed by Ehrenfried Pfieffer, who carried the discipline after Steiner's death. Pfieffer, who later moved to the US, has been identified as the main force in the coalescence of the organic agriculture movement.

The fifth chapter is titled 'The great humus controversy', and discusses the skepticism agricultural chemists and researchers felt for Howard's work on soil fertility, in particular, the value of humus in improving fertility. This chapter also discusses the founding of the Soil Association, whose formation was partly due to Howard's conversion of Lady Eve Balfour to an organic enthusiast. Five ideas underlay the founding of the Soil Association, all of which recognize the importance of soil fertility as well as a 'belief in a natural order', thus linking the beginnings of the English organic movement to Christianity.

The sixth chapter discusses briefly the organic movement in the United States. The influence of several people is featured: James Rodale, Louis Bromfield, Edward Faulkner and Paul Sears. Conford describes Rodale as 'spokesman for the cause of Howard and Pfieffer, forerunner of Carson's case against pesticides, critic of food additives, inspirer of the next generation of organic farmers and gardeners and popularizer of the organic cause through his magazines, books and plays'. The US organic movement was influenced by the British movement, largely through the relationship between Pfieffer (who had moved to the US) and Lady Eve Balfour, who spoke on several occasions about the Soil Association's work and environmental contamination caused by DDT.

The next two chapters outline the decline in rural life in England and English research on how organic food can support good health. The ninth chapter focuses on organic food, politics and economics: Conford firmly ties the beginnings of the organic movement to right-wing politics. He links more than seven major players in the British organic movement to the fascist and conservative movements. In the tenth chapter, he ties together his earlier

descriptions in the discussion of the 'heart' of the organic movement – the New English Weekly (NEW). The publication began in 1932, when the British government implemented a farm program, complete with subsidies, quotas and tariffs. The NEW cared about the decline of rural life, and believed England should pursue a policy of increasing the rural population that aimed for national self-sufficiency in agriculture. The NEW contained articles on soil erosion, soil fertility and human health issues, and had lengthy debates over the value of agricultural mechanization.

The eleventh chapter ties the organic movement to Christianity, through a common reverence for land and the 'natural order' of life. A strongly held belief by many Christians, Conford discusses, was that farming could make it possible to understand of the natural order of the world. Philip Mairet (founder of NEW) stated that harmony between man and nature was possible if man's relationship with God was similarly synchronized. William Temple believed that human activity must consider the 'whole economy of life', and that focusing strictly on the economic aspect would be ruinous.

All said, Conford's discussion of the beginnings of the organic movement is revolutionary, in the sense that he provides a new picture of how the organic industry began. Conford's story, which weaves across continents, personalities and philosophies, has a high level of detail, and is clearly not for the fainthearted. But those who are willing to enter into this challenging book will be rewarded by his discussion that travels to unexpected and, at times, incongruous places—India, the theosophical movement in Germany, and the conservative, fascist and Christian movements in Britain. For me, the idea that the organic industry is comprised of the meeting of these seemingly disparate strands of thought is appealing, in that I now see there is more richness to the organic industry than I once thought.

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